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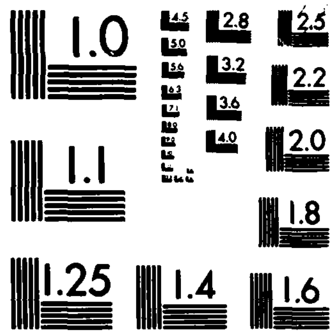

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Report DAAK70-79-C-0042F

DEVELOPMENT OF A HIGH EFFICIENCY COMPRESSOR/ EXPANDER FOR AN AIR CYCLE AIR CONDITIONING SYSTEM

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Final Report

Prepared for:
U.S. Army Mobility Equipment Research and Development Command
Ft. Belvoir, Virginia 22060

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SUMMARY

This document presents the methods and procedures used, and the results obtained, in the design, fabrication and testing of a rotary vane type compressor operated on air cycle thermodynamics. The history and results of the testing of a similar expander are summarized and the full report of that work is referenced. The machine design used was based on one patented by Ecton Corportion. The goal of the reported effort was to demonstrate the attainable efficiencies of these machines. Appropriate test rigs were assembled and the machines were tested at various operating conditions. The compressor testing did not achieve the full design speed because of time constraints but important data was obtained at 87% speed (3000 rpm). The maximum measured total efficiencies were 78% for the expander and 71% for the compressor. Various design improvements which may yield improved performance were identified and reported.

PREFACE

The reported effort was performed by the Ecton Corporation under U.S. Army Mobility Equipment Research and Development Command Contract DAAK70-79-C-0042. The MERADCOM Project Engineer was Mr. Robert A. Rhodes, Jr.

The Ecton Corportion Program Manager was Mr. Ronald E. Smolinski. The Project Engineer was also Mr. Ronald E. Smolinski until 12 April 1982 when Mr. Roger L. Summers assumed that duty.

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1. INTRODUCTION

The purpose of this contracted effort was to design, fabricate and test a rotary vaned compressor and to test an existing similar expander at conditions which would provide 18000 Btu/hr of cooling air to a military shelter. An interim report was published in December 1980 (Reference 1) and this document is the final report.

The rotary vane designs used in this effort were based upon a unique configuration patented by Ecton Corporation. The expander was the first working machine built with the new design and so many questions concerning the value of the design existed. A goal of this effort was to demonstrate the attainable efficiency levels of those first designs.

The bulk of existing and proposed shelter air conditioning systems operate on vapor cycle thermodynamics. The Ecton designs operate on air cycle thermodynamics. The comparative advantanges and disadvantages of the two methods are an ongoing debate within the industry. Air cycle claims advantages in system volume, weight, and reliability, logistics requirements, and damage tolerance. Vapor cycle claims a mature concept and better efficiency as its prime advantages. The goal, stated above, of demonstrating the air cycle efficiencies, is a required step to

better quantify the difference in performance of the air and vapor cycles.

The expander testing was performed earlier and reported in the Interim Report. Therefore, this report provides little additional information on the expander and pertains mostly to the design, fabrication and testing of the compressor. The report organization is consistant with MIL-STD-847 and the contract data item description DI-S-4057. The work accomplished is described in Section 2 (Investigation) and details of items of special interest and problems encountered are presented in Section 3 (Discussion). Supporting information including all recorded test data is provided in the appendices.

2. INVESTIGATION

This section contains a narrative description of the work accomplished. The methods and procedures used in design and fabrication are described. Special problems encountered are identified but their details are discussed in the next section (Discussion). The test procedures employed and the results obtained are discussed in this section.

2.1 Expander

2.1.1 History

The Model 161 Expander was designed and fabricated by Ecton Corporation prior to the start of this contract. Under this contracted effort, the expander was to be tested in a special test rig to obtain performance maps. That testing was completed prior to December 1980 and the results were reported in the Interim Report (Reference 1). For continunity a brief summary of that work is given below .

During the first phase of this contract the Model 161 Expander was evaluated for use in two configurations. Those were 1) an oil lubricated (closed cycle) system and 2) a dry lubricated (open cycle) system. The expander performance and reliability were predicted and compared for the two configurations. Also, the expander was tested in both an oil lubricated and dry lubricated configuration. The testing performed and the results obtained are

described in Reference 1. The recommendation documented in Reference 1 was that the oil lubricated system be chosen for further development instead of the dry lubricated system. The oil system was chosen for two primary reasons: (1) modulation of the system capacity is more easily done and (2) the development costs should be lower.

Performance analyses done at the start of this contract indicated that air leakage between the rotor face and endplate wall was a major contributor to the internal losses of the expander. That same analysis indicated that for an oil lubricated machine the existence of an oil film in that same gap would reduce the amount of the air leakage.

The expander was tested over a range of operating conditions. The tests were also run for a range of rotor to endplate clearances, to evaluate the effects of the internal leakages mentioned above. The test results confirmed the performance predictions of the effects of the rotor to endplate clearance.

The highest levels of efficiency attained in the testing were 78% for isentropic and 89% for volumetric efficiency. Over the range of shaft speed and pressure ratio tested the curves of efficiency were found to be nearly flat, straight lines. Several curves showing the variation of efficiency with the tested parameters were published in Reference 1.

2.1.2 Test Procedures and Results

The contracted expander testing had been completed prior to submission of the Interim Report (Reference 1) and the procedures and results of that testing were reported in Reference 1. However during review of those results it was discovered that an increase in expander efficiency might be obtained by using a lubricating oil of a lower viscosity than was used in the original test. It was expected that the lower oil viscosity would result in lower viscous drag losses thereby increasing the mechanical efficiency and thus the overall efficiency of the expander.

The expander was therefore reassembled to the test rig and Estrolene 10 oil was added to the system. (The original testing was done using Quaker State Automotive Engine Oil 10W-40.) However, at the beginning of the test, and before any test data was taken, the expander suffered a mechanical failure. Upon disassembly of the machine it was discovered that one vane axle had fractured and that the retaining ring and all the vane bushings, on the same end of the machine, had been damaged. All damage was confined to the end of the rotor having the broken axle and the vane axles, bushings and retaining rings on the opposite end of the rotor showed no indication of wear.

The complete set of expander vanes were sent to the University of Dayton Research Institute for a

failure analysis. Their study found inclusions in the vane material, which was made from cast aluminum, and they tested the remaining vane axles for breaking load. Their conclusion was that the failure was caused by an increased stress resulting from the stress riser of the inclusion of the vane material. Their recommendation was to fabricate the vanes from wrought material instead of the casting material.

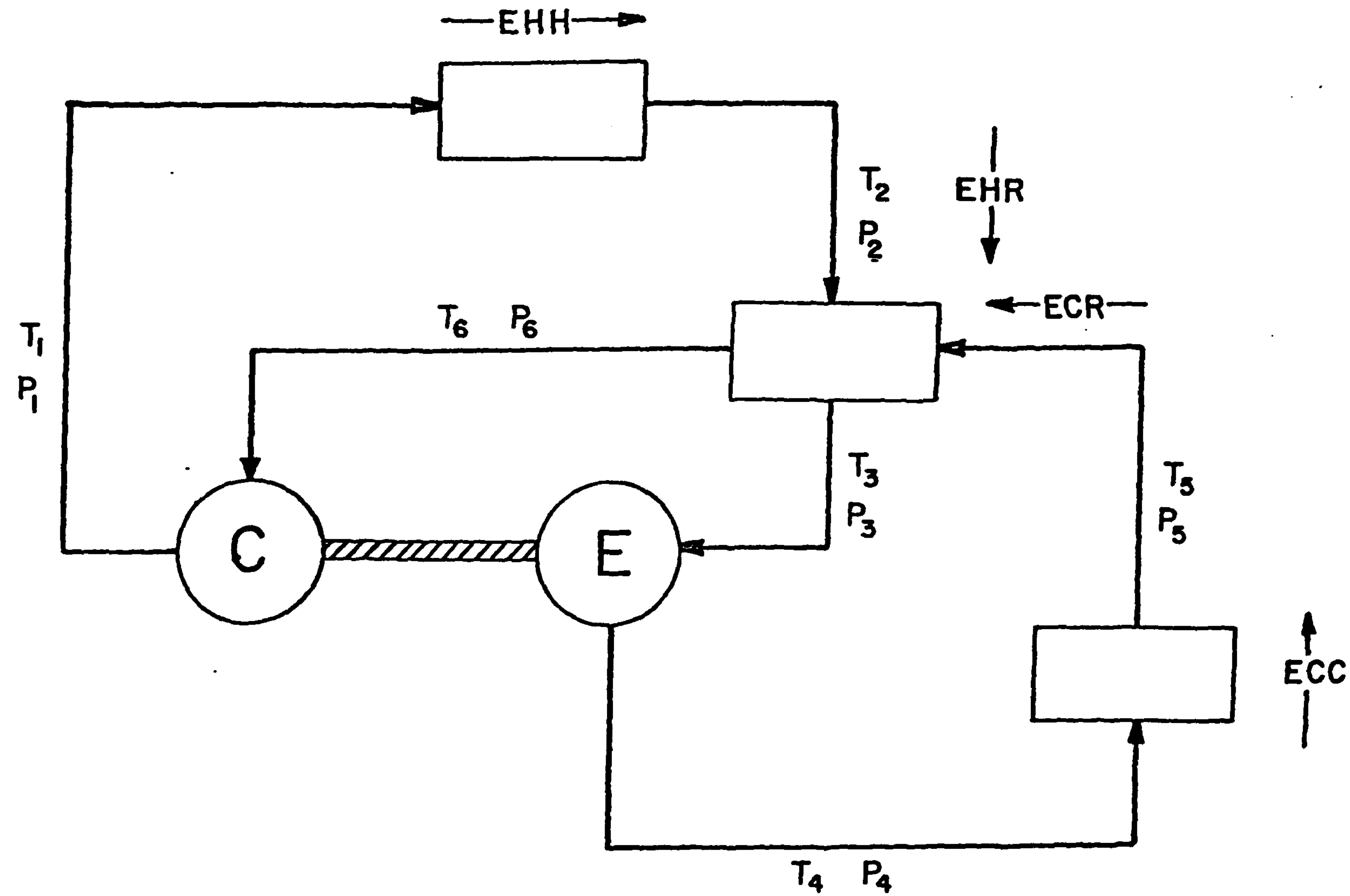
Complete details of the failure and the U.D.R.I failure analysis are discussed in Section 3.1.2. The U.D.R.I Failure Analysis report is included in Appendix A.

2.2 Compressor

2.2.1 Design

To start the design analysis it was necessary to establish the performance parameters for the compressor. Those parameters had to be compatible with the existing expander design when placed in a closed loop, oil lubricated system providing a cooling capacity of 18,000 Btu/hr. Preliminary estimates of the compressor and system parameters were determined using an Ecton computer program called ACAC. That program performs simple thermodynamic calculations for a closed loop system of components arranged as shown in Figure 2.1. The calculations are made over a range of compressor pressure ratios to allow selection of the best (preliminary) matched conditions which give the

CLOSED LOOP
AIR CYCLE



Closed Loop System Schematic
Figure 2.1

required system performance. The system conditions selected through that procedure are given in Table 2.1.

The preliminary operating conditions of the compressor were taken from Table 2.1 and then used as input for the CMP program to initially size the compressor. CMP is a proprietary compressor performance program. It predictes many parameters including required machine geometry, internal pressures and temperatures, flow rate, vane and rotor loads, bearing loads, efficiencies and power requirements. CMP is used in an iterative fashion with ACAC to better match the performance of the compressor to that of the system. A typical CMP input file is shown in Table 2.2, as reprinted by CMP. The variable name list for the CMP program is provided in Appendix B. The program yields output data for thermodynamic and structural parameters and typical output files are shown in Tables 2.3 and 2.4. The program will also provide many pages of extended output which define the thermodynamic and structural conditions at selected increments in the rotation of the compressor.

Based upon the above analysis, the compressor operating conditions to be used for the compressor mechanical design were selected. Those design conditions are listed in Table 2.5. Using those

conditions and the detailed information (extended output) obtained from the CMP program, a layout drawing

Table 2.1

Preliminary System Conditions

(From Program ACAC)

Item	Units	Value
T1	R	805
P1	Psia	66.1
T2	R	600
P2	Psia	66.0
T3	R	546
P3	Psia	65.9
T4	R	458
P4	Psia	27.8
T5	R	540
P5	Psia	27.7
T6	R	594
P6	Psia	27.6
ECC	--	.89
EHH	--	.93
ECR	--	.90
EHR	--	.90
VC1	Cubic inches	11.2
VE2	Cubic inches	7.1
MDOT	lbm/min	15.2
RPM	rpm	3450

Table 2.2

CMP Input File, Typical

```
BEGIN DESIGN POINT PERFORMANCE INPUTS                                                  PROGRAM CMP (VERS 1.04)
                                                                                       -----------------------
 COMPRESSOR SIMULATION
CAM BEARING=FAFNIR9310,,BUSHING VANE BEARING
MERADCOM COMPRESSOR DESIGN , ROTOR BEARING FAG6304

     VN            RVB            RCB           EC            ASR           VH            RI
   6.0000        0.26650        1.4173        0.35000       0.86210       1.9327        3.0000

    ACGR           HRO            HTH           RIMRO         RIMT          RIMW          RRO
   0.86210       0.28000        0.50000       0.28000       1.000000-04   0.30000       0.18000

     SH            SRO            STR           VRO           WAX           WBRG          PHUB
   0.00000       0.00000        1.0000        0.28000       5.280000-03   1.000000-04   42.000

    RLG            RPM             R            CP            FL            MU1           MU2
   4.8700        3450.0         53.300        0.24000       1.0000        9.000000-02   9.000000-02

    PCI            TCI            ACD           GAM           OGPM          OCP           SPGR
   27.550        594.00         5.1000        1.4000        1.000000-04   1.000000-04   1.000000-04

    BF1            CD             DM             E            FO            LEX           VISC          A123
 1.000000-04     2800.0         0.53300       1.1100        2.5000        3.0000        15.000        3.0000

    SCON           SLND           VTSC          RH            MURHF         VTSH          VT
   0.00000       0.00000        7.500000-02   2.7150        7.664000-05   0.00000       7.500000-02

    BFR            CDR            DMR           ER            FOR           LEXR          VISCR         AR123
 6.000000-04     3000.0         1.4173        1.1250        2.5000        3.0000        15.000        3.0000

    BFC            CDC            DMC           EEC           FOC           LEXC          VISCC         AC123
 6.000000-04     2510.0         2.4016        1.1250        2.5000        3.0000        15.000        3.0000

    EPS1           EPS2           EPS3          EPS4          EPS5          PEPS
 1.500000-03   1.500000-03    1.500000-03   1.000000-03   2.000000-03   0.18000

    IVRT           IVTA           AVRT          ME            MG            VTRAD         DELV
 4.512000-02   1.712000-04    0.14500       3.000000 07   9.090000 06   0.30000       0.96350

  JI           KODV           NSP           KODS          NPT           II
  30            0              0             1             1            10
```

Table 2.3

CMP Thermodynamic Output, Typical

BEGIN DESIGN POINT PERFORMANCE OUTPUTS

THERMODYNAMIC OUTPUTS

VC1	VC2	CVR				
11.398	6.0771	0.53318				
TC1	TC2	CTR	CDT	THUB		
598.12	769.41	1.2864	171.28	758.78		
PC1	PC2	PCD	CPR	POP	CDP	PHUB
27.550	66.468	65.545	2.3791	0.98611	37.995	43.122
CFMI	FLOCID	SCFM	FLOCA			
136.54	17.109	219.04	16.767			
WAS	WHI	WHD	WV2	WV4	WH	WCO
0.10059	0.10662	0.12582	5.209640-03	1.737060-02	0.14187	1.127030-02
ROLHP	RBRHPC	VWHP	VTHP	RHHP	VEHHP	CAMHP
7.878140-02	2.956790-02	0.20083	6.177850-02	0.10555	6.966890-02	0.10308
TORQAV	SHP	HPCI	HPCA	HPC	SUMHP	
614.49	33.637	-15.826	-16.632	-17.281	-0.64936	
VOLEFF	MECEFF	ADEFF	COMEFF			
0.98001	0.96242	0.95156	0.91581			

Table 2.4

CMP Structural Output, Typical

STRUCTURAL OUTPUTS

WV	WS	RWT	WHSG	WRIM	SUMWT
0.19766	0.00000	24.023	28.461	2.81258D-05	53.734
RVAV	FCAV	BL10	RVL10	RVHR10	
25166.	87.475	65160.	11816.	7825.7	
FRCAV	BRL10	RRL10	RRHR10		
470.96	3746.0	478.24	2310.4		
FCCAV1	BCL10	RCL10	RCHR10		
32.015	6.98394D 06	8.91614D 05	4.30731D 06		
VMRFMX	VMRFMN	VMRSMX	VMRSMN	VMTBM	JVMTBM
2.50015D-04	0.00000	1.24715D-04	0.00000	3.85603D-04	229
VWPVCM	VWPVAV	VVMAX	VTPVCM	VTPVAV	SVMAX
20342.	4088.8	645.77	0.00000	0.00000	6683.7

Table 2.5

Compressor Design Conditions

Item	Description	Units	Value
RPM	Shaft speed	rpm	3450
VC1	Inlet volume	cubic inches	11.4
RLG	Rotor length	inches	4.87
RI	Rotor radius	inches	3.00
EC	Eccentricity	inches	0.35
TCI	Inlet temperature	F	134
PCI	Inlet pressure	psia	27.6
CPR	Pressure ratio	--	2.38
FLOCA	Actual flow rate	lbm/min	16.8

was generated.

During the design and material selection for the compressor, Invar 36 was chosen as the material for the stator housing and endplate. Invar was chosen because it has a very low thermal expansion coefficient compared to 416 stainless steel, which had been used in previous machines. The reduced thermal expansion would provide better clearance control and result in smaller running clearances. Therefore internal leakages would be reduced and the machine operating efficiencies would be increased. It was predicted that this improvement would be significant.

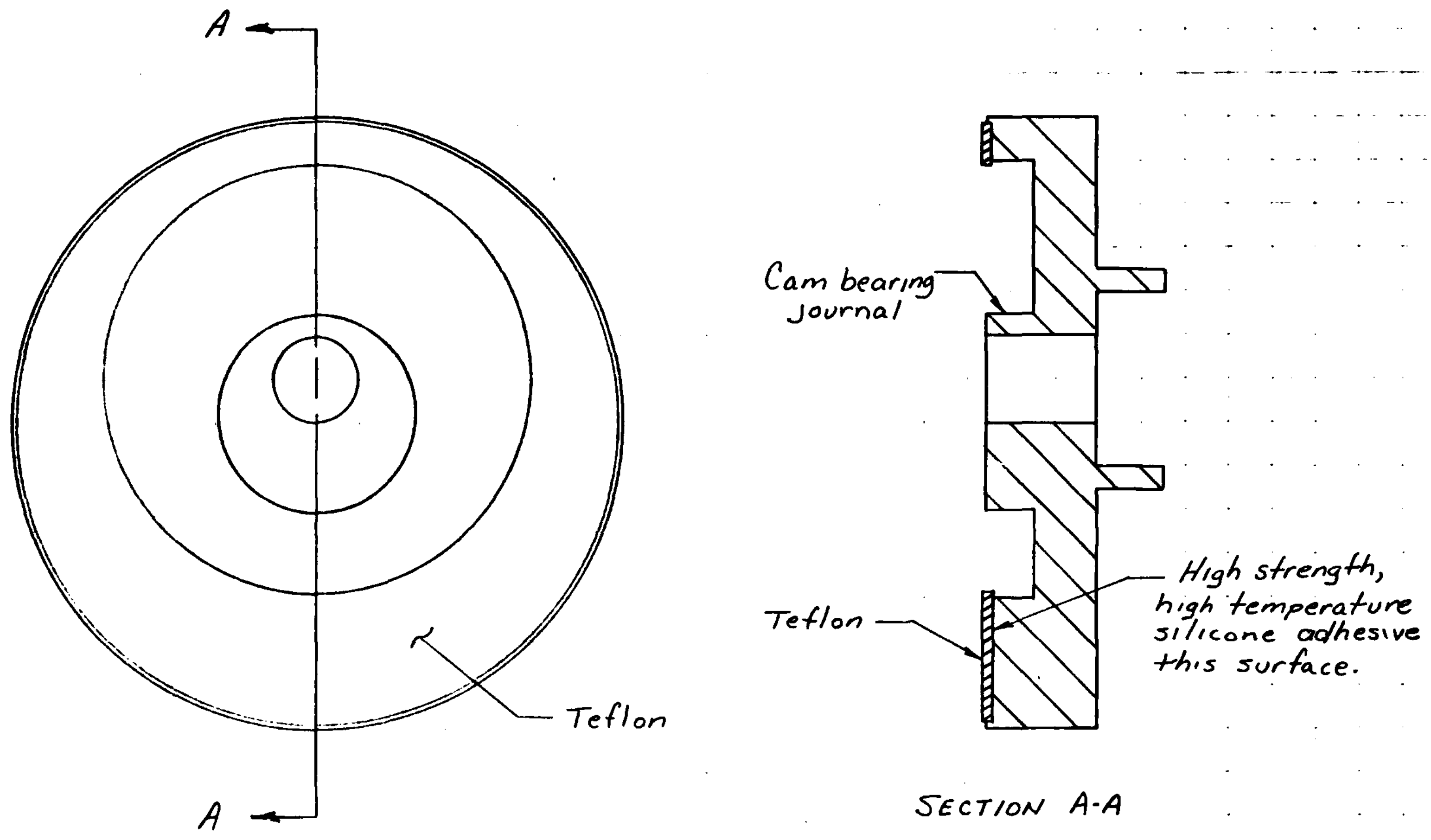
After completion of the layout drawing, detail drawings were made and fabrication was started. However, just prior to the scheduled delivery of the Invar 36 material, the material supplier revealed that Invar 36 was no longer available from the mill. It was obvious that a substitute material would have to be chosen and because the detail design of the other components of the compressor accounted for the low thermal expansion of the Invar, that detail design of those components would have to be redone. Further design and fabrication of the compressor was therefore halted until a replacement material could be chosen and redesign of the affected components completed.

The material chosen to replace the Invar was 416 stainless steel which had been used in previous Ecton

machines. The increased thermal expansion of that material would cause larger internal clearances within the machine and would thus prevent attaining the higher efficiencies as predicted. To maintain the rotor to endplate clearance near the originally designed values, abradable wear plates were added to the surfaces of the two endplates. Teflon was chosen as the wear plate material. A counterbore was added to the endplate surface. Then a 0.30 inch thick sheet of teflon was bonded to the endplate using a high temperature, high strength silicone adhesive. The teflon surface was ground to a dimension which would provide a close clearance with the rotor at the operating condition. A sketch of the endplate/wear plate geometry is given in Figure 2.2.

The design of other components was rechecked to determine if revisions were required to accommodate the new thermal growth pattern expected from the new stator material. Dimensional changes were required for the shaft, rotor segments and vanes.

Except for the shaft and the vanes, the compressor parts are subjected to operating loads which cause relatively low stress levels. There are two reasons for that fact. First, most components were designed for minimum deflection under load to provide better running clearance control. Secondly, no attempt was made to minimize mass because no machine weight limit



Endplate/Wear Plate Geometry

Figure 2.2

was specified.

A conservative calculation of the shaft factor of safety as designed is shown in Figure 2.3.

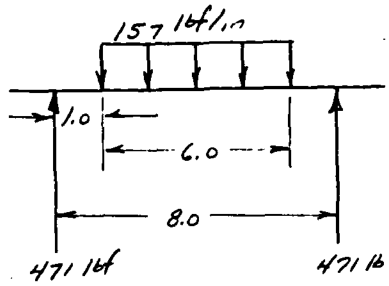
During the early design stages a vane deflection calculation was performed. The calculation was made using the NASTRAN program which employs finite element analysis. The loads used in the analysis were taken from the output of the CMP program. The results of the deflection calculation are depicted in Figure 2.4. The boundary condition, at the axle, is not definitely known and so the calculation was made for both a fixed end and a simply supported end. A fixed end condition would exist if the radial clearance between the cam bearing, vane bushing, and retaining ring were zero disallowing the vane bushing to rotate laterally in response to vane bending. A simply supported end condition would result if that clearance were sufficient to allow deflection of the vane and axle without causing the radial clearance to disappear. Because a zero clearance assembly is not practicable and because a simply supported vane would deflect much more than a fixed one, the eventual design involved radial clearances which would cause a boundary condition between the two extremes. That is, at the operating condition a radial clearance allowed the vane to bend slightly before the vane axle engaged the retaining ring. The resulting boundary conditon should

From CMP: Brg loads = 471 lbf

S_y (416 S/S) = 145,000 lbf/in^2
S_e (416 S/S) ~ 72,500 lbf/in^2

Speed = 3450 Rpm, Power ~ 18hp → T = 329 in lbf

$$\text{Max } M = 471(4) - \frac{157(3)^2}{2} = 1178 \text{ in lbf}$$



$$n = \frac{\pi d^3}{32} \Bigg/ \sqrt{\left(\frac{T}{S_y}\right)^2 + \left(\frac{M}{S_e}\right)^2} \qquad (1)$$

d ~ .787" (bearing journal dia - does not account for hex area)

$$n = \frac{\pi (.787)^3}{32} \Bigg/ \sqrt{\left(\frac{329}{145 \times 10^3}\right)^2 + \left(\frac{1178}{72.5 \times 10^3}\right)^2}$$

$$n = 2.9$$

(1) Soderberg Eqn:
Ref Shigley, Joseph Edward, Mechanical Engineering Design, 3rd Ed., McGraw Hill, New York.

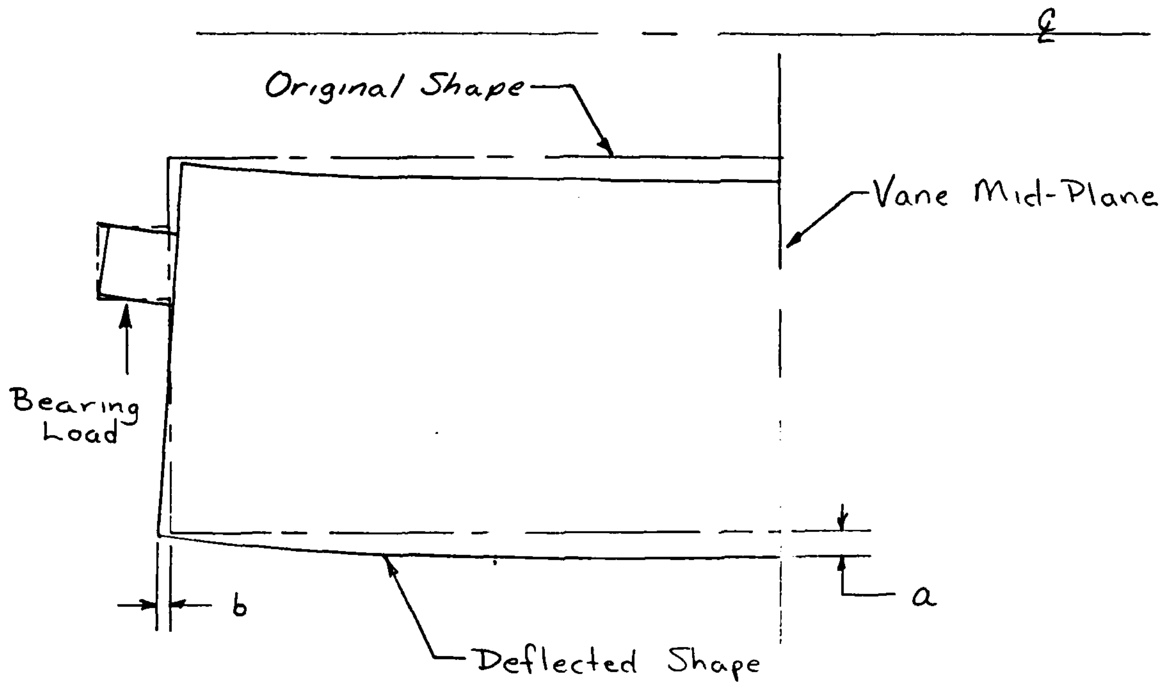
Shaft Factor of Safety Caluclation
Figure 2.3

then be one causing less deflection than a simple condition. Therefore, the actual vane deflection was expected to be between the two values shown in Figure 2.4.

A later calculation of vane axle stress was made for the same two boundary conditions. Figure 2.5 depicts the model used in the calculation and shows the resulting stress values. A stress concentration factor of 2.6 was used to account for the vane axle bushing stop geometry. The calculation, made for a steel vane, predicted stresses on the order of 31,000 psi.

Aluminum was rejected as a candidate material for the compressor vanes because the high temperatures attained inside the machine (approximately 300 F) significantly degrade the fatigue life of that material. To provide adequate fatigue life, 4140 steel was chosen as the vane material. A calculation of the vane factor of safety considering fatigue is shown in Figure 2.6.

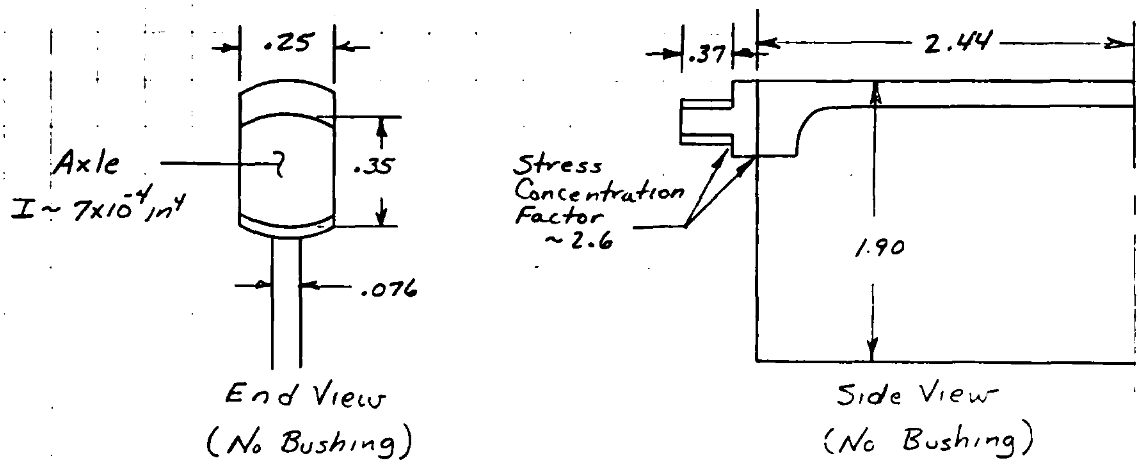
The effects of many forces and parameters (e.g. vane loads, vane axle boundary condition, vane stiffness, retaining ring thermal growth, and stator housing thermal growth) combine to cause the "as built" clearance between the vane tips and the stator housing wall to change significantly during operation of the compressor. Although some of those causes and effects were analyzed, as described above, experience has shown



Boundary Condition	Deflection ~ 10^{-3} inches a	b
Fixed	1.0	0.2
Simple Support	2.1	0.2

Vane material: Steel
Vane dimensions: .075 X 1.93 X 4.87 (inches)
Bearing load: 100 lbf

Vane Deflection Estimates
Figure 2.4



Fixed End:

$$M \sim 28 \text{ in lbf}$$

$$\sigma_F = \frac{2.6(28)(.35/2)}{7\times10^{-4}}$$

$$\sigma_F \sim 18{,}200 \text{ lbf/in}^2$$

Vane Mat'l: 4140 Steel
($S_y \sim 195\times10^3$ lbf/in^2)

Bearing Load: 128 lbf

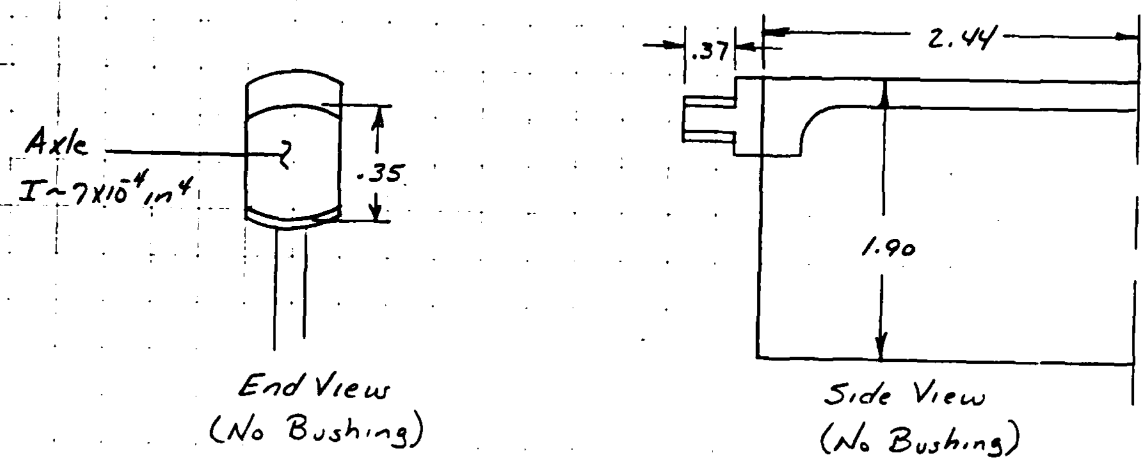
Simple Support:

$$M \sim 47 \text{ in lbf}$$

$$\sigma_S = \frac{2.6(47)(.35/2)}{7\times10^{-4}}$$

$$\sigma_S \sim 30{,}600 \text{ lbf/in}^2$$

Vane Axle Stress Estimates
Figure 2.5



Endurance strength corrections:[1]

Ka (ground surface)	~	.9
Kb (< .3" mat'l size)	~	1
Kc (90% reliability)	~	.897
Kd (300 °F temp.)	~	.82
Ke (stress conc. factor)	~	1/2.6
Kf (misc.)	~	1

Vane Mat'l: 4140 Steel,
$S_u = 210{,}000$ lbf/in²
$S_y = 195{,}000$ lbf/in²
$S_e' \sim S_u/2$

$$\therefore \quad S_e = [.9(1)(.897)(.82)/2.6](210{,}000/2) = 26{,}700 \text{ lbf/in}^2$$

	Max	Min
Bearing load : (lbf)	128	56
Moment : (in-lbf)	47	21
Stress : (lbf/in²)	11750	5250

$\sigma_{avg} = 8500 \quad \sigma_r = 6500$

$$F.S. = \left[\frac{\sigma_{avg}}{S_y} + \frac{\sigma_{range}}{S_e}\right]^{-1} \quad (2)$$

$$F.S. = 3.5$$

(1) Ref: Shigley, Mechanical Engineering Design, 3rd Ed.
(2) Ref: Spotts, M.F., Design of Machine Elements, 5th Ed.

Vane Factor of Safety Calculation
Figure 2.6

that the total combined effects can not be accurately predicted without extensive analysis (which was beyond the scope of this contract). Therefore, the adopted method of providing controlled vane tip clearances involved designing the vanes to initially rub against the stator housing during operation, and then manually grinding the vane tips between tests at increasing speeds until the compressor could be operated at the design speed without vane tip rubbing. That procedure had been successfully employed at Ecton in earlier test programs on rotary vaned machines.

2.2.2 Fabrication

Following the initial design of the compressor the detail drawings were released for fabrication in September 1980. Fabrication of several of the components was started shortly thereafter but fabrication of the stator housing and endplates was delayed because of late delivery of material. By January 1981 it had been discovered that the chosen material for the stator housing and endplates, Invar 36, was no longer available (reference Section 2.2.1) and that a redesign would be required. Because design of other components of the compressor were based upon the assumption of the use of Invar 36, it was apparent that use of a replacement material would require changes in the detail design of those other components. Therefore, all fabrication on the compressor parts was

halted in January 1981. Subsequently, 416 stainless steel was chosen to replace the Invar 36 and redesign of the compressor parts was effected (reference Section 2.2.1). After revision of the compressor design, the restart of fabrication was delayed by contract modifications, to increase the funding for fabrication, and therefore fabrication did not restart until 5 November 1981.

Fabrication of the vanes, which included hard chrome plating of the surfaces, was first completed in January 1982. However, inspection of the vanes revealed that the plating had chipped in several locations along the vane edges and additionally that most of the vane bodies had warped during the plating process. For those reasons the vanes were rejected, requiring new vanes to be fabricated. A new vendor was selected for the vane fabrication and the requirement of hard chrome plating was removed. Those changes resulted in successful fabrication of the compressor vanes. The problems encountered with the vane fabrication are discussed in more detail in Section 3.2.3.

The redesign of the endplate, required by the change in material to 416 stainless steel, involved the use of a teflon wear surface bonded to the endplate surface with a high strength silicone adhesive. To accommodate the teflon, a shallow counterbore was added

to the endplate surface. Then a 0.03 inch thick teflon sheet was bonded to the surface and accurately ground to a dimension which would ultimately allow contact between the rotor and teflon. The use of a teflon wear surface is discussed in further detail in Section 3.2.2.

Other than experiencing numerous delays in delivery of a number of the compressor parts, fabrication was otherwise uneventful. Component fabrication was completed and the compressor assembly was started in April 1982. No significant design modifications were required during assembly of the machine.

2.2.3 Test Procedures and Results

The procedure and system used to test the compressor were very similar to those used for the expander which were described in Section 2.1.2 and the Interim Report (Reference 1). A closed loop test rig arrangement was assembled to accomodate the compressor. The necessary features of filtration, pressure regulation, heat rejection, oil separation and temperature and pressure instrumentation were included. The instrumentation was connected to Ecton's Automatic Data Acquisition System and certain redundant instrumentation was provided for direct visual reading. Power was provided to the compressor by a portable hydraulic power unit. That unit supplied power to a

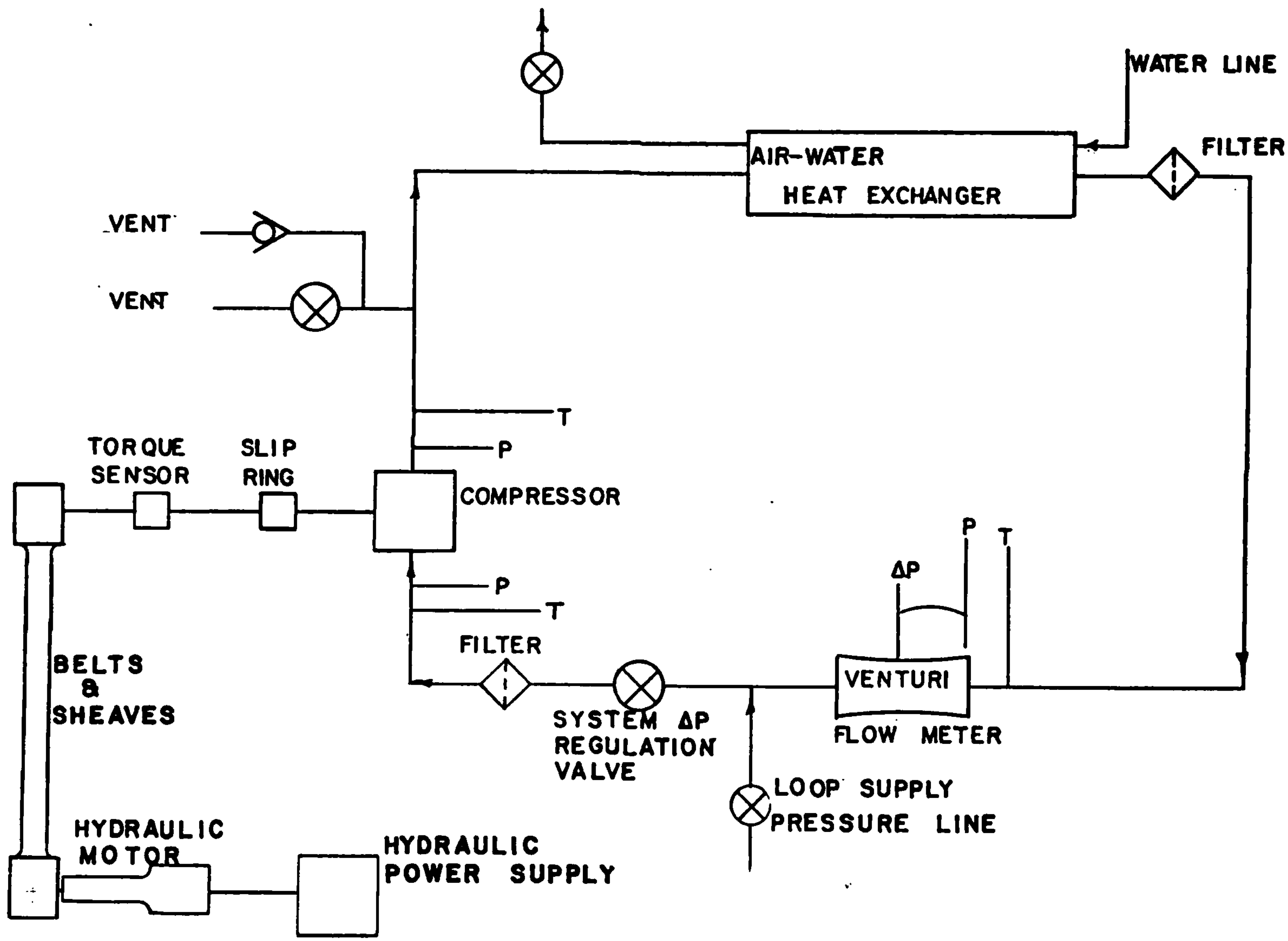
hydraulic motor which was made part of the test rig set up. The lubricating oil used in the compressor was Kendall SAE 30 Heavy Duty Automotive Engine Oil. A schematic of the compressor test rig is shown in Figure 2.7.

At the start of the compressor testing, the test rig had a couple of features additional to those of Figure 2.7. An early concern of the closed loop test system was separation of the oil from the air stream after the compressor discharge and ahead of the heat exchangers. The concern was that if not collected upstream, the oil would significantly affect the performance of the heat exchangers. Therefore, to aid in oil separation a large receiver tank was placed between the compressor and the heat exchangers. The flow of air into the tank was arranged to cause the oil to strike the receiver walls and then to flow vertically through the receiver at a very low velocity. Unfortunately, that arrangement was not effective in causing oil separation. Additionally, vibration of the receiver caused excessive noise at many compressor speeds. Also, the performance of the two heat exchangers was found to be more than adequate. Therefore, the receiver was removed from the test system.

The second early difference with Figure 2.7 involved a second heat exchanger. The two heat

Figure 2.7

COMPRESSOR TEST RIG SYSTEM



exchangers mentioned above easily rejected the heat load, and in fact such a small flow of cooling water was required that the control of the loop air temperature was difficult. Therefore, when the receiver was removed, one heat exchanger was also removed. With that change the required cooling water flow increased and yielded acceptable control of the loop air temperature. Separation of the oil was thereafter adequately performed by the filters shown in Figure 2.7.

During testing the compressor was operated at predetermined speeds which were controlled by the setting of the hydraulic power unit. The pressure drop in the closed loop system was manipulated by adjusting a valve in the system thus controlling the pressure ratio across the machine. Test data was then recorded for a matrix of conditions of compressor speeds and pressure ratios.

The data, which was recorded by the automatic data acquisition system, included compressor inlet and outlet temperatures and pressures, flow meter inlet and throat static pressures, compressor shaft speed and input torque. Additional data which was recorded periodically, manually, to guide in the operation of the test, included endplate exterior temperature, compressor vibration level, oil supply flow rates, and inlet oil temperature. (The compressor test

instrumentation is discussed in detail in Section 3.3.2.) To insure that data was taken only at equilibrium conditions, the compressor exit air temperature was monitored following any control adjustments and data was only recorded after that temperature ceased to change.

At frequent intervals during each test run, the instrumented parameters being monitored by the data acquisition system were displayed on the computer video terminal. After a steady state conditon was attained the monitored data was both printed on computer paper and stored on the computer diskette. A typical listing of the printed data is shown in Table 2.6. The variable name list for the automatic data acquistion system is provided in Appendix C and the complete listing of printed test data and results is provided in Appendix D.

The Automatic Data Acquisition system and program also performed certain data reduction procedures. Equations of the venturi flow meter calibration were included in the program. Also, equations to determine the compressor pressure ratio and to predict the ideal air flow rate and ideal power requirements, based on the measured speed, were included. Finally, equations relating the predicted ideal conditions to the actual measured conditions were included to calculate the volumetric efficiency and the total (referred to as

Table 2.6

Test Data Printout, Typical

8 June 1982

```
Y159:16:37:40

0PO= 32.772 01PEI= 26.783 02PEO= 34.715 03DELP=   .732 04TORQ= 10.723
06EXC10V=  9.995 RPM= 1740.  14TROT1=134.300 15TROT2=121.200
0TO= 69.500 11TEI= 70.400 12TEO=144.400 13THUB= 85.000
PR=1.296 RPM=1740.  A-E=.552 V-E=.788 T-E=.481

Y159:16:38:00

0PO= 32.839 01PEI= 26.847 02PEO= 34.774 03DELP=   .729 04TORQ= 10.732
06EXC10V=  9.996 RPM= 1739.  14TROT1=134.000 15TROT2=122.800
0TO= 69.500 11TEI= 70.400 12TEO=144.400 13THUB= 85.000
PR=1.295 RPM=1739.  A-E=.550 V-E=.786 T-E=.480

Y159:16:42:52

0PO= 34.952 01PEI= 26.860 02PEO= 36.725 03DELP=   .648 04TORQ= 11.913
06EXC10V=  9.996 RPM= 1730.  14TROT1=131.700 15TROT2=126.100
0TO= 69.800 11TEI= 70.700 12TEO=155.600 13THUB= 85.000
PR=1.367 RPM=1730.  A-E=.585 V-E=.771 T-E=.516

Y159:16:43:12

0PO= 34.992 01PEI= 26.908 02PEO= 36.782 03DELP=   .647 04TORQ= 11.895
06EXC10V=  9.996 RPM= 1732.  14TROT1=128.500 15TROT2=129.500
0TO= 69.700 11TEI= 70.700 12TEO=155.800 13THUB= 85.000
PR=1.367 RPM=1732.  A-E=.583 V-E=.769 T-E=.516

Y159:16:47:52

0PO= 37.983 01PEI= 26.813 02PEO= 39.632 03DELP=   .566 04TORQ= 13.720
06EXC10V=  9.995 RPM= 1722.  14TROT1=148.400 15TROT2=167.800
0TO= 70.200 11TEI= 71.000 12TEO=171.600 13THUB= 84.800
PR=1.478 RPM=1722.  A-E=.624 V-E=.758 T-E=.556

Y159:16:48:12

0PO= 38.077 01PEI= 26.877 02PEO= 39.726 03DELP=   .565 04TORQ= 13.741
06EXC10V=  9.994 RPM= 1721.  14TROT1=144.600 15TROT2=162.400
0TO= 70.200 11TEI= 71.100 12TEO=171.700 13THUB= 84.800
PR=1.478 RPM=1721.  A-E=.624 V-E=.758 T-E=.556
```

isentropic) efficiency. The printed format of those calculation results are also shown in Table 2.6. The data reduction equations used in the program are given in Appendix E.

The purpose of this contracted effort was to demonstrate improved (over previous industry experience) compressor efficiencies for a rotary vane type compressor at a 3450 rpm, 2.4 pressure ratio condition. Therefore, during all the testing the major interest was to increase the compressor speed toward the design speed and to adjust the rotor to endplate clearance (by shimming) and the vane tip to stator housing clearance (by grinding the vane tips) to obtain the highest possible efficiency levels. As planned (reference Section 2.2.1) the compressor speed was incrementally increased until vane tip rubbing was detected (by sound). Upon detecting such rubbing the compressor was disassembled and the vane tips were ground to shorten the vane. At times, evidence of non-uniform rubbing against the stator housing was found along the housing length. In those areas, some material was removed from the housing by grinding. As the speed was increased the calculated levels of efficiency were documented. To further increase those efficiency levels, the shims controlling the rotor to endplate build clearance were adjusted during certain disassemblies.

As discussed in Sections 3.2.4 through 3.2.7, numerous difficulties were encountered during the run-up testing of the compressor. By the time those problems were resolved, considerable manhours had been spent and the intended schedule for completion of the testing had been missed. At the time when the contract resources were exhausted, the run-up testing had progressed to 3000 rpm, just short of the 3450 rpm design condition. Therefore, the results obtained and reported here were limited to off design operation. The results presented here do, however, show the relationship of the efficiencies for many conditions. Because the testing was not completed, the best possible efficiency of which the compressor is capable was not demonstrated.

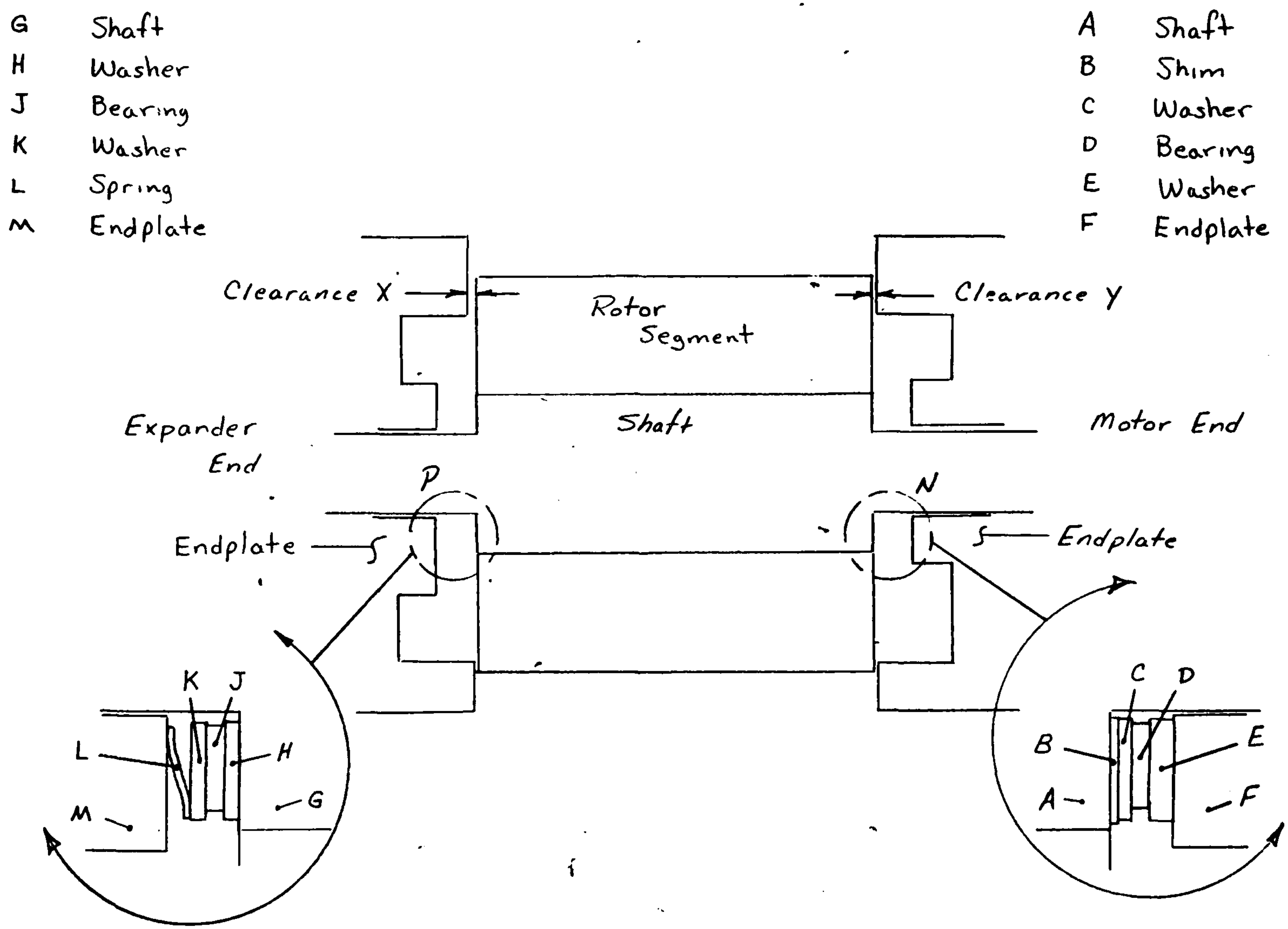
As explained above, data was taken for a matrix of speed, pressure ratio and rotor to endplate build clearance. The rotor to endplate clerance is reported as x/y where x is the build clearance on the motor driven end and y is the build clearance on the expander driven end of the compressor. The rotor was positioned relative to the two endplates using a thrust bearing on one end and a thrust bearing and a preload spring on the other end of the rotor (shaft). On the motor driven end of the compressor the rotor to endplate position is always controlled by the thrust bearing. Therefore, the effects of relative thermal growth

between the rotor and stator housing apply mainly to the rotor to endplate clearance at the opposite end of the machine. That is why the build clearance is larger on the expander driven end of the compressor. Figure 2.8 illustrates those features just described. The results reportd here are therefore identified with specific rotor to endplate build clearances (e.g. .002/.006), as well as speed and pressure ratio.

The reduced data generated by the Automatic Data Aquistion System was summarized and listed in Appendix F. Test conditions were run over the ranges of: 1) 1712 to 3006 rpm, 2) 1.29 to 2.30 pressure ratio, and 3) rotor to endplate clearances of .006/.007 to .002/.0065.

The first useful data was taken on 8 June 1982. All testing that day was done with a 72F compressor inlet temperature. (The design point inlet temperature is 134F.) The results of the 8 June testing are plotted in Figures 2.9, 2.10 and 2.11. Those curves show the variation of efficiency with both pressure ratio and speed. As the speed was increased the efficiency levels increased. Also, as the speed increased, the pressure ratio at which the isentropic (total) efficiency peaked was increased.

Subsequent testing through 11 June 1982 was geared towards running at increasing speeds while monitoring signs (sounds) for vane tip rubbing (reference Section



Compressor Rotor/Endplate Clearance Sketch

Figure 2.8

Figure 2.9
Volumetric Efficiency
8 June 1982

Rotor/Endplate Clearance: .006/.007
Inlet Temperature: 72°F

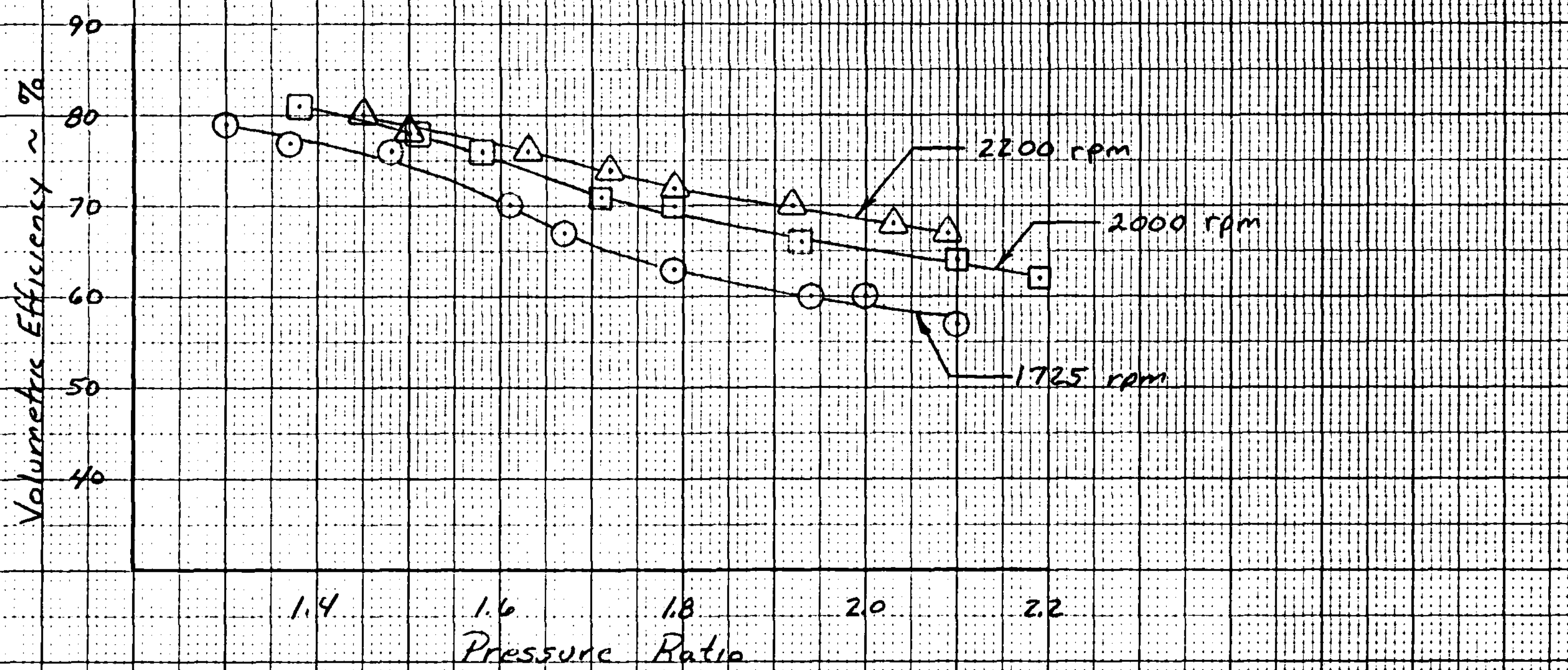


Figure 2.10
Adiabatic Efficiency
8 June 1982

Rotor/Endplate Clearance: .006/.007
Inlet Temperature : 72F

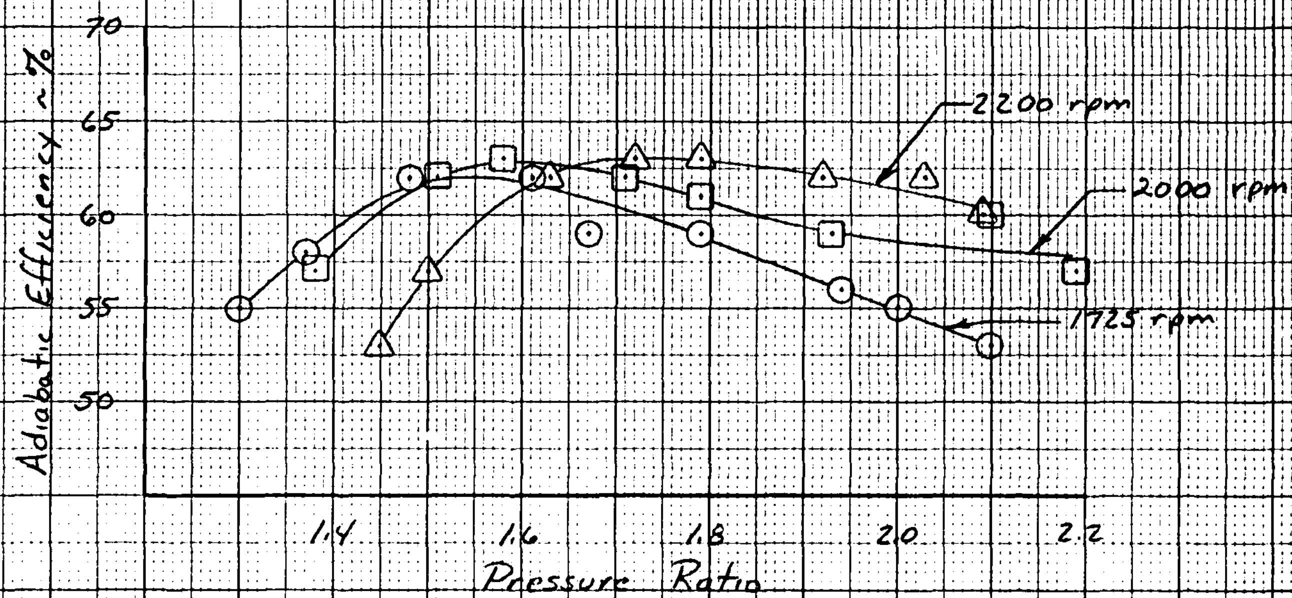
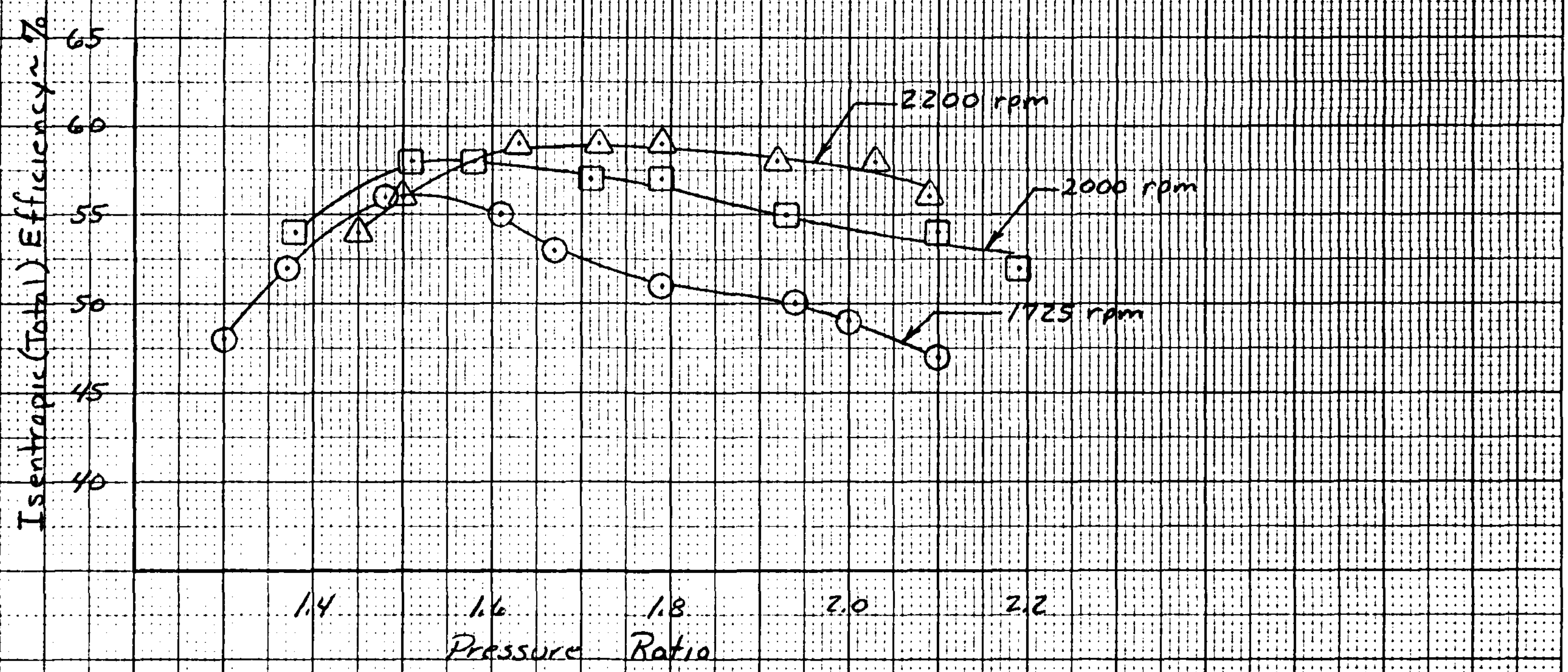


Figure 2.11
Isentropic (Total) Efficiency
8 June 1982

Rotor/Endplate Clearance : .006/.007
Inlet Temperature : 72F



2.2.1). During disassemblies for vane tip grinding, opportunity was taken to reduce the rotor to endplate build clearances in attempts to increase the efficiency levels. The results of that testing are plotted in Figures 2.12, 2.13 and 2.14. Those curves show that efficiency improvements were generally achieved with the smaller clearances. An exception was the testing of 11 June which showed drops in the adiabatic and total efficiences. No clear reason was found for that slip in performance and later testing, on 17 and 18 June, showed that the efficiencies increased again to above the 10 June levels.

By 17 June 1982, sufficient vane tip rework had been performed to allowable operation of the compressor at speeds above 2500 rpm. On that and the following day the compressor was tested at speeds from 2000 to 3000 rpm and at compressor inlet temperatures up to 141 F. The data taken on 18 June was divided into three pressure ratio groupings and plotted in Figures 2.15, 2.16 and 2.17. Those figures show that the highest efficiencies demonstrated were: Volumetric of 87%, Adiabatic of 76%, and Isentropic (total) of 71%.

In addition to the test matrix described above an additional matrix of variable oil flow over a range of speeds and pressure ratios was taken. The intent of that test was to determine if a relationship between efficiency and the amount of oil supply could be

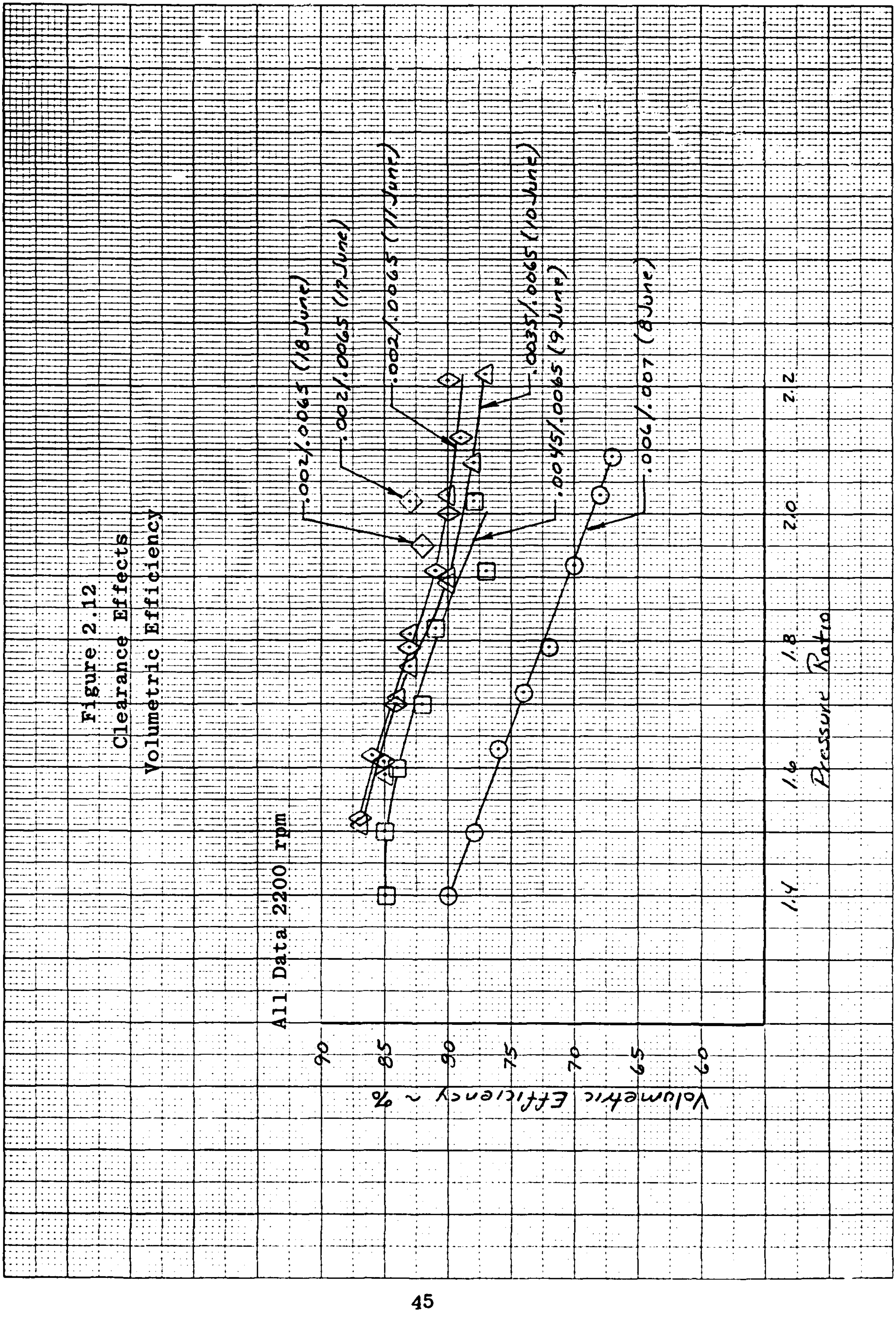


Figure 2.12
Clearance Effects
Volumetric Efficiency

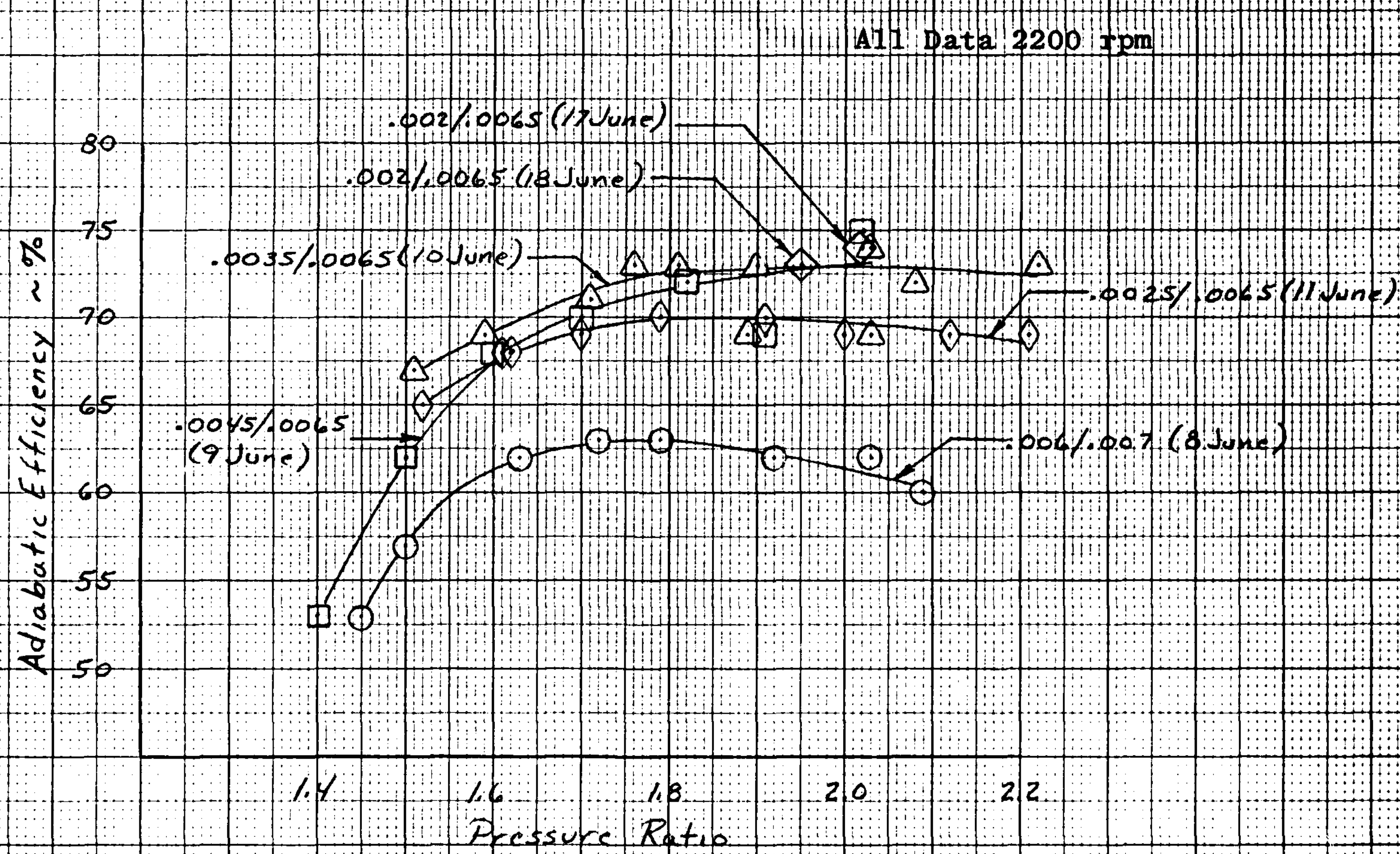


Figure 2.13
Clearance Effects
Adiabatic Efficiency

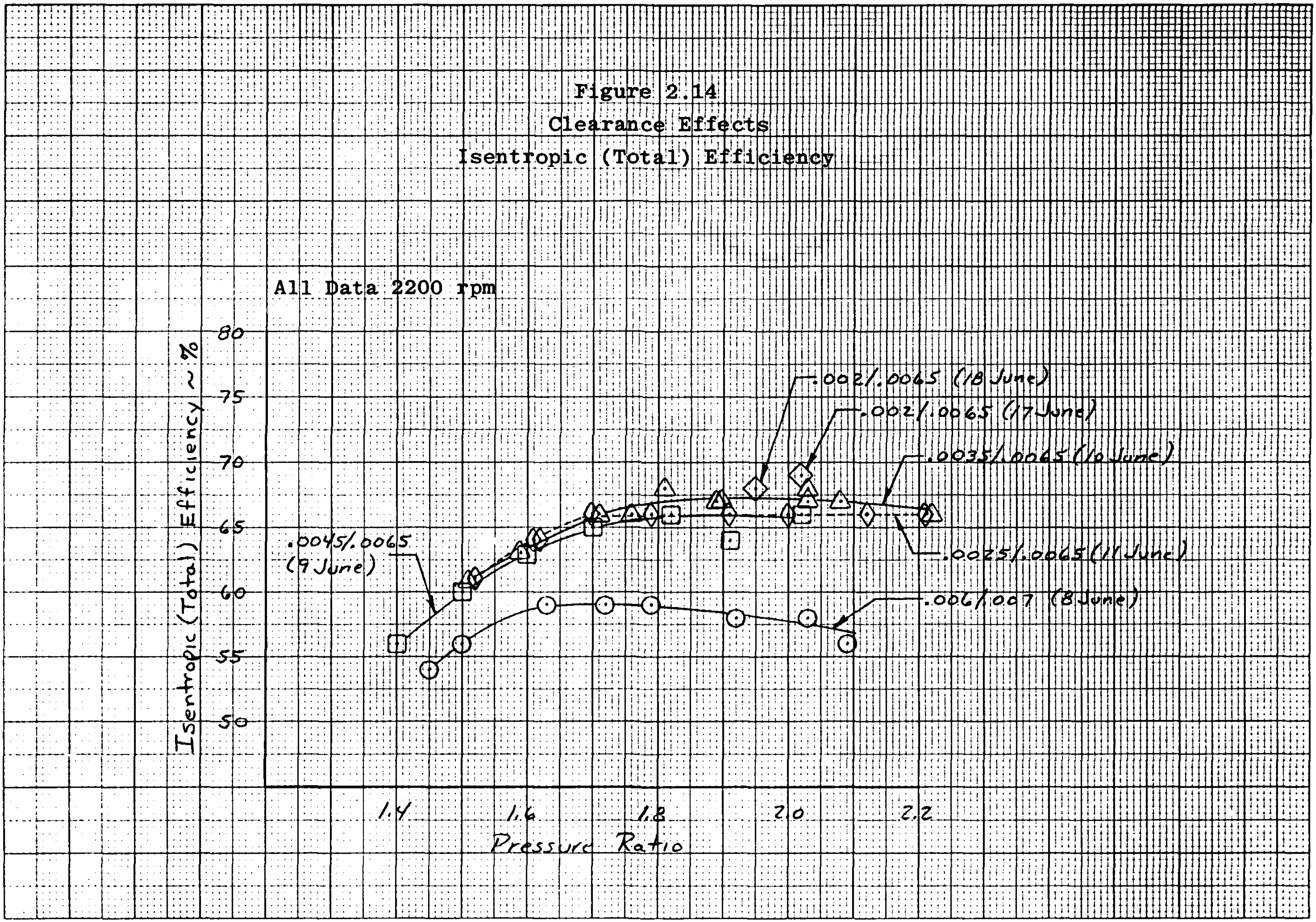


Figure 2.14
Clearance Effects
Isentropic (Total) Efficiency

Figure 2.15
Volumetric Efficiency
18 June 1982

Rotor/Endplate Clearance: .002/.0065
Inlet Temperature : 131-141F

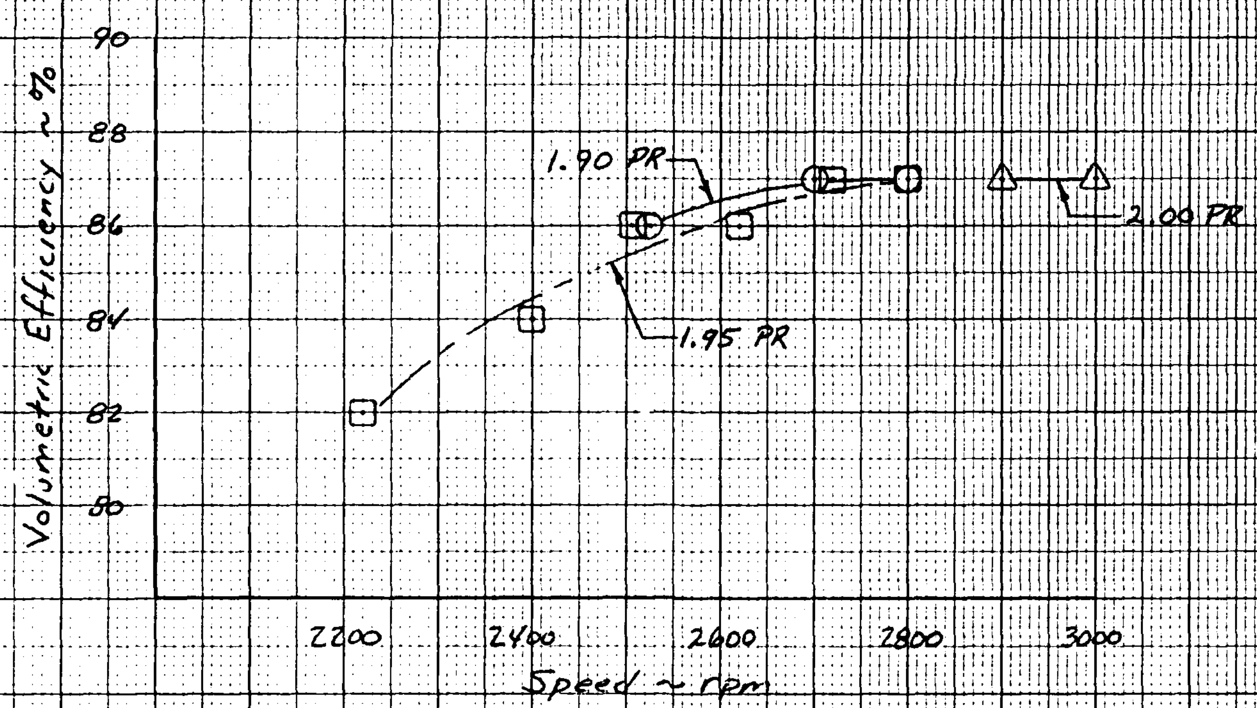


Figure 2.16
Adiabatic Efficiency
18 June 1982

Rotor/Endplate Clearance: .002/.0065
Inlet Temperature : 131-141F

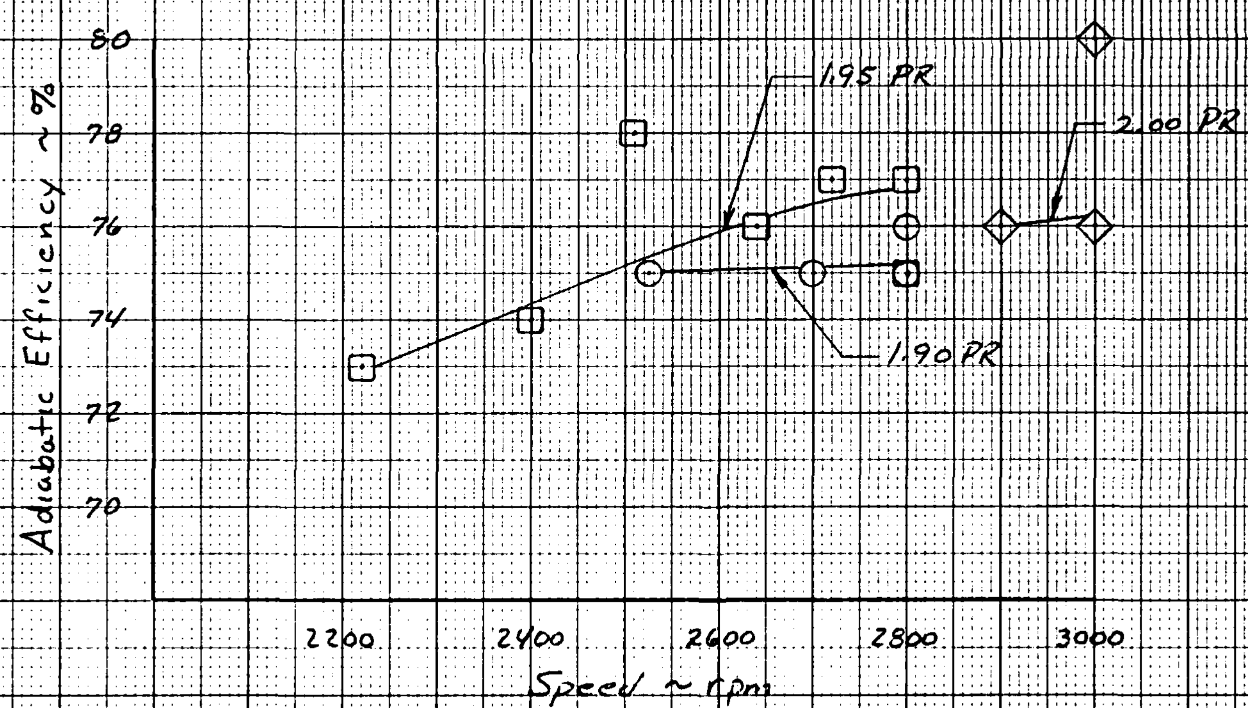
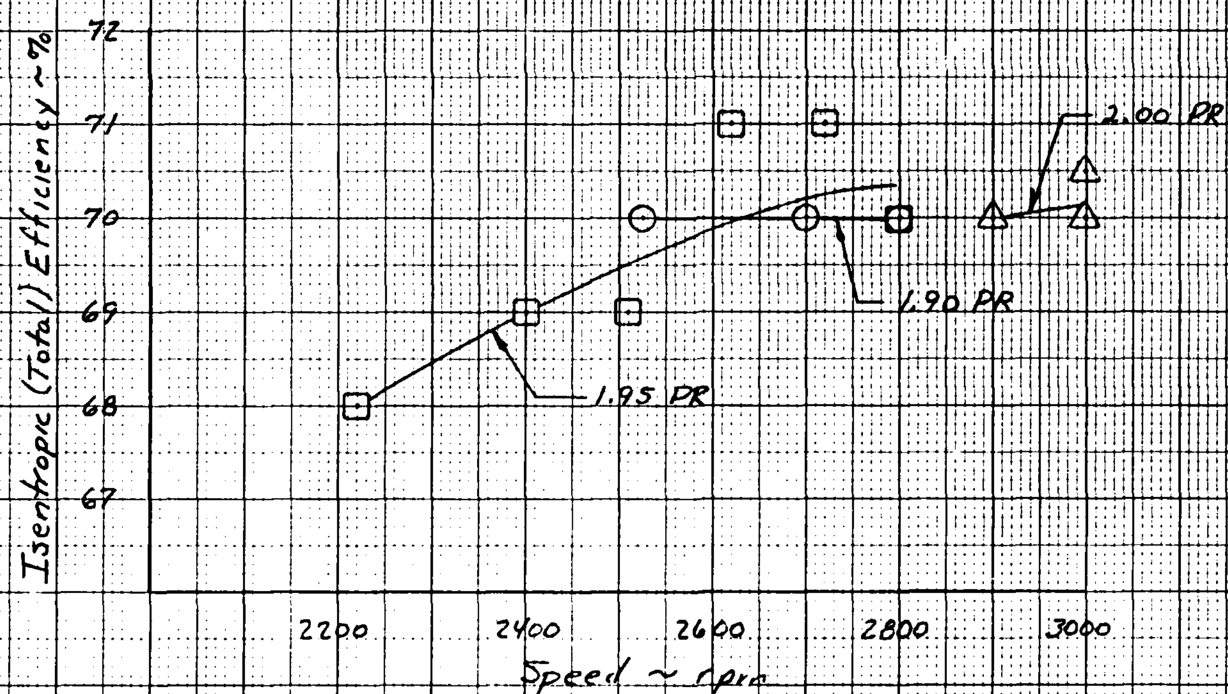


Figure 2.17
Isentropic (Total) Efficiency
18 June 1982

Rotor/Endplate Clearance: .002/.0065
Inlet Temperature : 131-141F



detected. At various conditions of compressor speed and pressure ratio the oil flow delivery rate to the two endplates and the shaft center was varied individually and then collectively. Previous test experience with oil flooded rotary vane machines had shown a perceptible variation of performance (efficiency) with the amount of oil delivered to the machine. The test was conducted on 10 June 1982 and the data is summarized in Appendix F. The oil flow reported as x, y, z (e.g. 7, 11, 11) refers to the shaft, expander driven end endplate, and motor driven end endplate delivered oil flow rate. The quantity of oil flow is determined by scaling from the known condition that a 10 reading on oil flow equals approximately 70 cc/hr. Test data was taken over a range of total (i.e. x+y+z) flow rate of approximately 100 to 420 cc/hr. The matrix of oil flow conditions was limited to avoid any oil system induced problems because numerous difficulties had already delayed the test schedule. The result was that the data collected on 17 June 1982 was inconclusive in identifying the suspected relationship described above. A few points of improvement in certain efficiencies can be seen in the data (reference Appendix F) but the data is too sparce to confirm a trend.

While running at speeds above 2700 rpm on 18 June 1982, a "higher than normal" vibration was sensed at

the OD of the motor driven end endplate. The method of detecting the vibration was by hand feel by sound detection through a screw driver held to the ear and touching the point of interest. Both methods had been used at all previous operating speeds and so a more precise inspection was demanded in response to the "sensed" change. The Balancing Company Inc. of Vandalia, Ohio, was contracted to perform a vibration test. The machine was operated at 2800 rpm and the vibration displacement and velocity were measured. The recorded data of that inspection is given in Table 2.7. The measured vibration was in the normal range for this type of equipment and so no further concern was given to the vibration.

After disassembly of the compressor on 19 June 1982, the two retaining rings were found to be discolored. The discoloration, which indicated that the retaining rings were subjected to much higher temperaures than expected, is discussed in detail in Section 3.2.7. A fix for the discoloration problem was conceived but was never implemented because work was stopped on the contract on 21 June 1982. Prior to that date however the compressor was reassembled, without any rework, and then run to 2800 rpm and a 2.0 pressure ratio to confirm proper assembly. No test data was taken during that run-up.

THE BALANCING COMPANY, INC.

VIBRATION ANALYSIS

Table 2.7

FOR: Ecton Corp. DATE: 18 / June / 1982

ATTENTION:

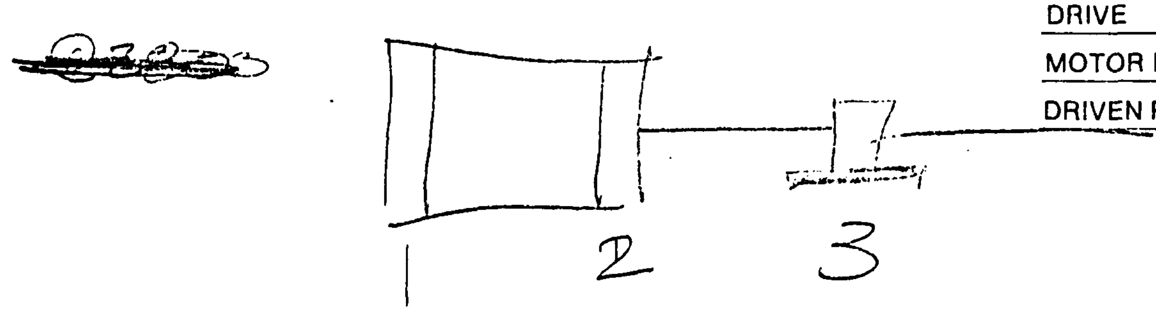
THE EQUIPMENT:

LOCATION:

DRIVE

MOTOR RPM

DRIVEN RPM 2800



SKETCH SHOWS PICKUP LOCATIONS

PICK UP LOCATION	VELOCITY/DISPLACEMENT			NOTES:
	HORIZONTAL	VERTICAL	AXIAL	
1	.20	.07	.04	FILTER IN DISPL.
2	.20	.13	.04	RPM = 2805
3	.15	.13	.10	
1	.85@10K	1.8@1K	1.9@2.8K	
2	1.0@8K	2.2@3K	1.3@5K	FILTER OUT
3	.8@15K	3.6@2.8K	1.0@9K	DISPL.
1	.4@35K	.2@60K	.3@30K	
2	.35@40K	.3@35K	.4@35K	FILTER OUT
3	.10@50K	.5@25K	.5@35K	VEL.
1	.30	.10	.08	
2	.30	.20	.28	FILTER IN VEL.
3	.35	.25	.35	RPM = 2800

BALCO 898 Center Dr., Vandalia, Ohio 45377
513/898-9111

FIELD SERVICE ENGINEER

3. DISCUSSION

Details of the problems encountered and of items of special interest, including the instrumentation and test apparatus, are discussed in this section.

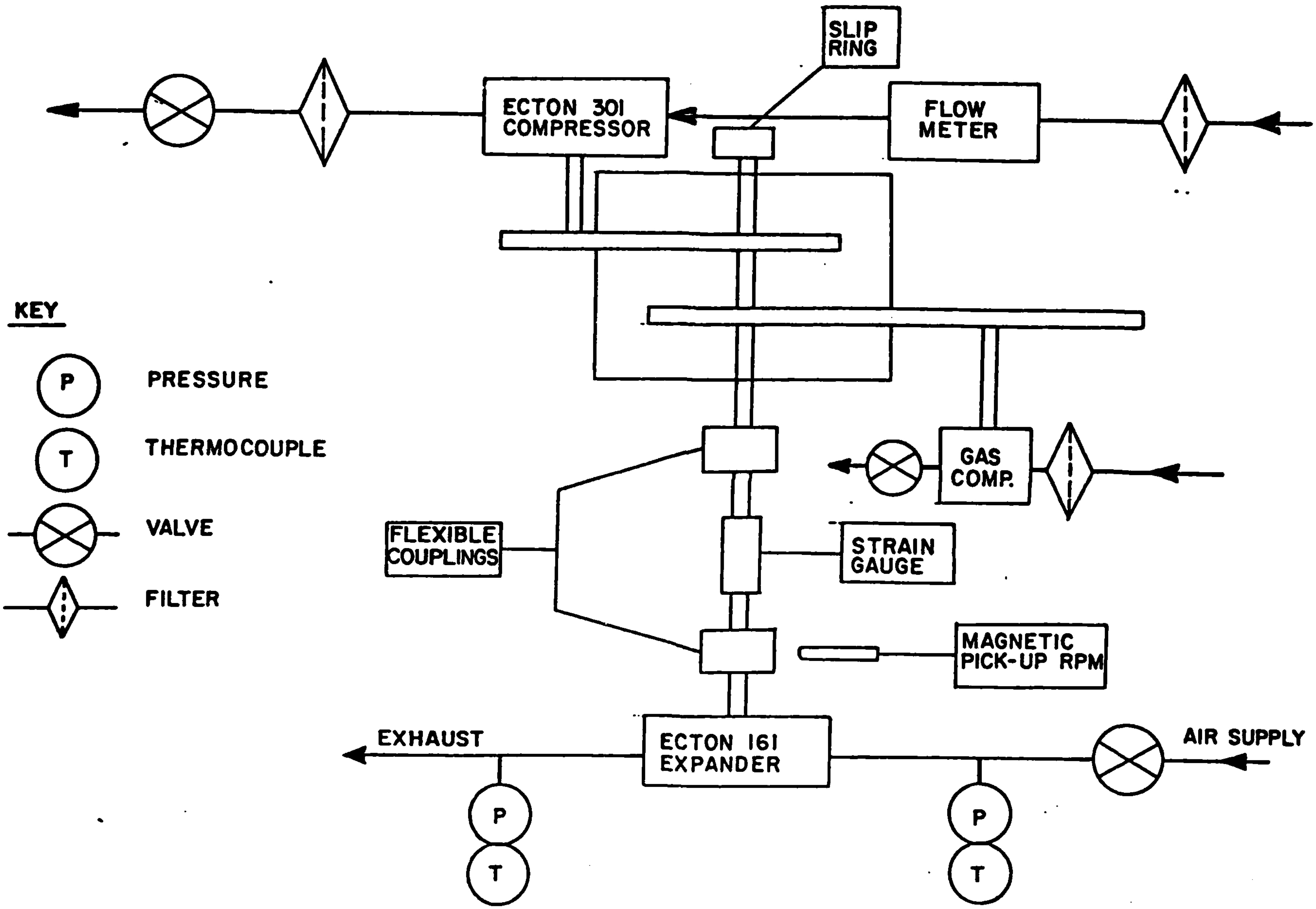
3.1. Expander

3.1.1 Testing

The expander was tested in 1980 and reported on in the Interim Report (Reference 1). The measured maximum efficiency of the expander as reported in the Interim Report was 78%. However, to achieve the contract goal of a COP of 1.0, an efficiency of 82% is required for both the compressor and expander (Reference 1). In the testing performed prior to the Interim Report, the internal clearances of the expander were controlled and minimized as much as possible while still avoiding extensive design changes. Therefore no further opportunity existed (within the current design) to improve the overall efficiency of the expander by reducing internal clearances. It was decided then to improve the overall efficiency of the machine by reducing the mechanical losses. Mechanical losses consist of friction losses in the bearings, vane/rotor interface, and bushing/retaining ring interface. Air and lubrication viscous pumping losses are also considered mechanical losses. Air viscous pumping losses are typically low compared to the other losses in such machines and because the leakage flows had

already been minimized it was believed that little margin for improvement in the air pumping losses was available. Based upon the minimum wear experienced during the testing of the expander, it was apparent that at least adequate lubrication was being delivered to the rubbing interfaces. Although the margin of safety in that lubrication system was not known it was decided to attempt to reduce the oil viscous losses by using a lubricant of lower viscosity. The lower viscosity might lead to increased friction at the rubbing interfaces named above but it was expected that the improvement in viscous losses would overcome that loss. The plan was to rerun certain original test points with a new oil. Estrolene 10 was chosen as the new lubricant.

The expander was reassembled into its original test rig, which is shown in Figure 3.1, and Estrolene 10 was added. The intent was to repeat the test conditions of the original test program. However prior to reaching the first performance condition of the test program and before any data was taken the expander experienced a mechanical failure. Disassembly and inspection revealed that a vane axle had broken from the vane body. Significant damage was also suffered by the remaining vane bushings and the retaining ring on the same end of the machine as the vane axle failure. The vane axle failure is discussed in more detail in



Expander Test Rig, Schematic

Figure 3.1

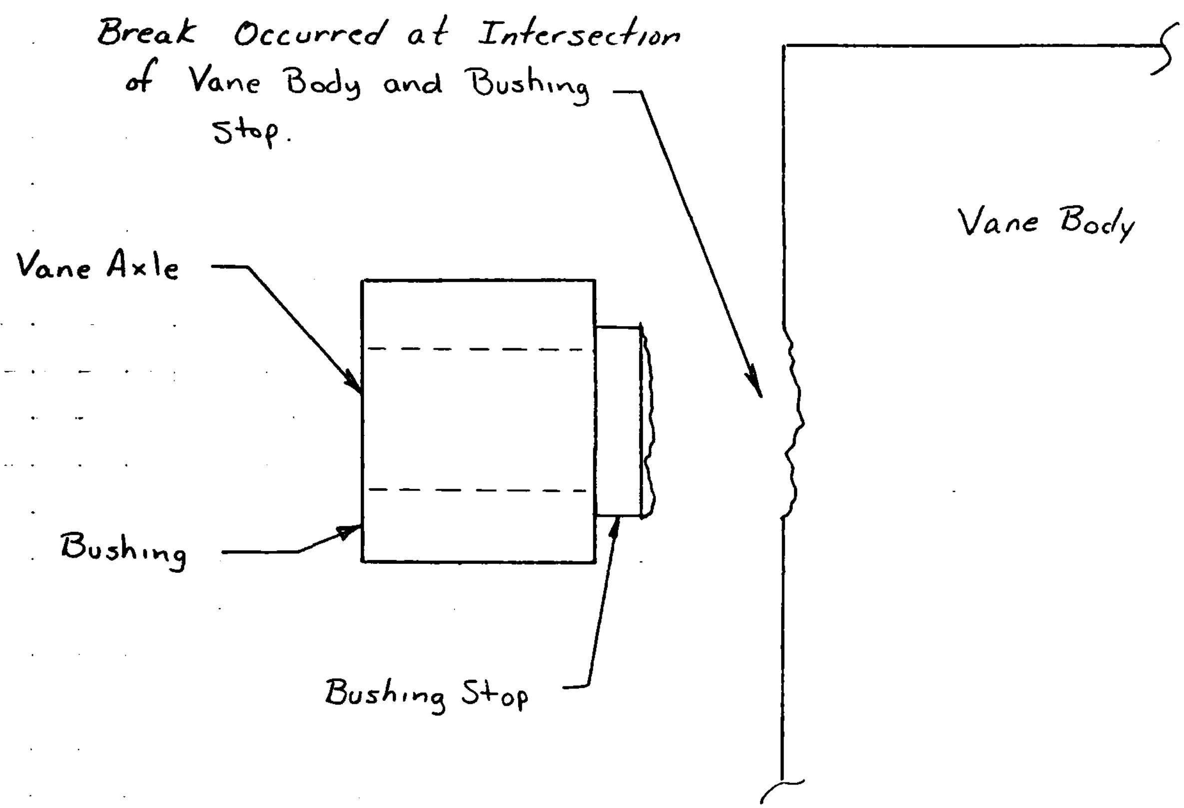
Section 3.1.2.

Replacement parts were fabricated for the expander. The machine was assembled after the compressor testing had ended. The expander was then run up with no load to a speed of 2800 rpm to confirm a proper assembly. No test data was recorded during that run-up. No vane tip rubbing was detected during the run-up.

3.1.2 Vane Axle Failure

In attempts to demonstrate a higher expander efficiency than the 78% demonstrated at the time of the Interim Report (Reference 1) an additional expander test was planned (reference Section 3.1.1). The new test was to be a repeat of previous test conditions with the only change being the use of a lubricating oil of lower viscosity. However as the expander was being run up in speed at the beginning of the test and before any new test data was taken, the expander experienced a mechancial failure.

Upon disassembly and inspection it was found that one vane axle had broken from its vane body. The sketch in Figure 3.2 depicts the location of the failure relative to the bushing and the vane geometry. The bushings of the other five vanes were also severely damaged and were found to have rotated on their axles. The retaining ring on that same end of the machine also had visible signs of excessive wear.



Vane Axle Failure, Sketch
Figure 3.2

On the opposite end of the machine no wear or damage was visible on either the bushings or the retaining ring. The wear surface on those items appeared to be more brightly polished than the nonrubbing surfaces but no measurable (by micrometer) wear could be detected.

Based upon the comparison of conditions of the two ends of the expander, and because the one end was in excellent conditon, it is believed that the primary failure was not directly associated with the lubricating oil. The first impression was that the primary failure involved fracture of the one axle and that the damage to the other bushings and the retaining ring was then a result of that primary failure.

To better identify the nature and cause of the failure the six vanes and the damaged retaining ring were sent to the University of Dayton Research Institute for inspection and mechanical testing. The fractured surfaces of the failed axle and vane were inspected using a scanning electron microscope and energy dispersion x-ray spectrometer. That inspection revealed the existence of several shrinkage cavities which were created during the cooling of the casting of the vane material. The conclusion was that the cavities reduced the cross sectional area of the axle and also caused stresses to concentrate at the cavities leading to an axle stress in excess of that

anticipated.

At U.D.R.I. fracture tests were performed on the remaining eleven axles. Five of the axles were loaded parallel to the vane body and six were load perpendicular to the body. The applied load was increased gradually until the vane axle fractured and the failure loads were recorded. The average fracture load was 346 pounds with a standard deviation of plus or minus 15.2 pounds. The orientation of the load showed no statistical effect on the strength of the axle. The variation of the fracture load was considered nominal.

A review of the original expander design data showed that the vane would be subjected to a load of approximately 55 pounds and so the eleven tested vane axles would have been adequate for the application. It was therefore concluded that the vane axle failure was caused by the poor casting quality which affected only one axle. The recommendation made by U.D.R.I. and adopted by Ecton was that wrought material be used for fabrication of any future vanes. The complete U.D.R.I. report is provided in Appendix A.

Replacement vanes, bushings and a retaining ring were fabricated for the expander. The expander was assembled and run up to 2800 rpm with the new components but no test data was obtained and so the question of improving efficiency by reducing oil

viscosity was not answered in this contracted effort.

3.2 Compressor

3.2.1 Material Selection

Because of the circumferential variation in the internal temperatures of the compressor, the stator housing metal temperature varies considerably around the circumference of the machine. That nonsymmeterical temperature causes the stator to grow more on the exit port side of the machine than on the inlet side. The nonsymmetric axial growth then forces the endplates to sit tilted relative to the ends of the rotor causing a nonuniform clearance between the rotor and endplates. The magnitude of the axial growth of the stator, which is proportional to the thermal expansion of the stator housing material, dictates requirements for design to determine build dimensions which will accommodate the stator housing thermal growth. In addition, the radial growth of the stator is also nonsymmetric for the same reasons as above and that causes a variable vane tip clearance around the machine.

To minimize the effects of the thermal growth of the stator housing, Ecton's previous compressor designs have employed 416 stainless steel as the stator housing material. Compared to several other stainless steels which could be used in this application 416 has a relatively low coefficient of thermal expansion. For comparison, the thermal coefficient of expansion is

given for a number of materials in Table 3.1 below.

Table 3.1

Thermal Coefficient of Expansion, Typical Values

Material	Coefficient (Micro in/in/F)
416	5.5
17-4 PH	6.0
304	9.6
316	9.4

The coefficient of thermal expansion of the 416 is considerably lower than that of the 300 series stainless steels and is slightly lower than that of the precipitation hardened stainless steels. Because of that comparison and also because 416 is more favorable in price and machineability, 416 S/S was used in previous compressor designs.

Subsequent performance testing of those designs confirmed the significant impact of internal leakage upon a compressor's performance. Based upon that experience it was determined that running clearances should be further reduced in future designs. A high priority was therefore given on this program to using a design which would further minimize the effects of the stator housing growth. That goal was apparently reached when a material called Invar 36, having a

thermal coefficent of expansion of approximately 0.9 micro in/in/F, was found. Although the Invar material was more costly and less machineable than the 416 base line material, the Invar was chosen as the stator housing and endplate material for the compressor. Prior to the design commitment, the details of cost and availability were supposedly resolved and the design of the compressor continued. However, as the delivery date of the Invar material approached, the supplier revealed that the small quantity of Invar which was required for this program could not be obtained at any price. Efforts to locate the material elsewhere were unsuccessful and so a change in the selected material for the stator housing and endplate was required.

To minimize any further delay of the compressor housing fabrication, which had already been delayed by the lack of material, no additonal material selection analysis was performed. The stator housing material specification was simply changed to that of 416 stainless steel and an order for the material was placed immediately. Because the change in the stator housing material would result in a change in the thermal growth of the unit and thus involve the clearances with other components, it became necessary to redo a major portion of the detail design of the stator, endplates, shaft, rotor segments and vanes. The rework of the design and then the process of

securing new fabrication quotations resulted in a four month delay in the fabrication of the compressor.

Although the efforts to investigate the potential of minimizing internal running clearances were interupted on this program it is still important that such a question be studied and in fact will probably be necessary for further improvements of the rotory vane compressor efficiency.

3.2.2 Vane Fabrication Difficulties

Because of the internal high temperatures of the compressor, aluminum was rejected as a candidate vane material because of its limited fatigue life at those operating temperatures. The material chosen for the vane was 4140 steel. To improve the surface finish and hardness of the vane, which would lead to minimum wear of the vane against the rotor surface, the vane was to be chrome plated. That material selection and surface treatment had been used on previous compressor designs.

During the plating process of the vanes the vendor reported having difficulties in applying the required chrome plating. One problem was reported to be the fact that full surface plating of the vane was required and that therefore no reference surface was available to subsequently check the thickness of the plating or the location of the substrate material below the plating. That problem was apparently solved by a processing sequence whereby a reference surface was

established and so fabrication of the vanes continued. However, after receiving the plated vanes the manufacturer determined that the applied chrome plating had numerous flaws. The thickness of the chrome plating was not constant over the total surface of the vane and it was extremely excessive in some areas of the vane. Attempts to grind the excess plating were made but were unsuccessful when it was determine that to yield the required overall vane dimensions it would be necessary to expose some of the substrate material in certain areas of the vane body. That was apparently due to the misalignment of the part relative to the plating envelope and to warpage of the substrate material during the plating process. Because of those several problems the entire set of compressor vanes were rejected and scrapped.

For fabrication of replacement vanes another vendor was selected. To avoid the multiple problems of the chrome plating process the requirement of the chrome plating of the vanes was removed. Although such action did compromise the intent of minimizing wear at the vane rotor interface it was a necessary action to keep the overall program within the schedule. Fabrication of the vanes proceeded without major problems and the complete vane set was ultimately inspected and accepted.

During post test inspections of the compressor,

the vanes were checked for signs of wear on the side surfaces which rub the rotor segments. No evidence of excessive wear was found. The machine failure which involved a vane to rotor rubbing interface (reference Section 3.2.6) was caused by a mechanical feature and was not directly caused by the lack of chrome plating on the vane.

The numerous problems which led to the scrapping of the first set of vanes may have several causes including design features, chrome plating processing, and control of the fabrication procedure. However it is not believed that the problem invalidates the use of such chrome plated steels for the vanes. The advantages of the hard surface and low surface finish are desirable to reduce wear rate and so the use of chrome plated steel should again be considered and investigated.

3.2.3 Teflon Wear Surface

After the stator housing material was changed to 416 stainless steel it was necessary to redesign the rotor and endplate to provide adequate running clearances. Because of the higher thermal coefficient of expansion of 416 (over that of Invar) it was not possible to simply design sufficient build clearances to accomodate the thermal growth and to yield the close running clearances required. It was therefore conceived that an interface material be used as an

abradable wear surface on the face of the endplate. Then, as the relative thermal growth of the stator and rotor caused the rotor to endplate clearance to close down, the rotor face could actually wear away the abradable surface. Thus, the machine would actually adjust itself to the appropriate geometry and running clearances.

A search of abradable materials was initiated and the several characteristics of such materials were evaluated. In choosing a suitable material the primary concerns were (1) abradability, (2) thermal stability, (3)adhesiveness to the endplate and (4) the nature of the abradable material and its effects upon the bearings and other machine componets. Because this redesign was causing a constant slip in schedule, the search was necessarily restrained. It was quickly determined that teflon would satisfy the four concerns listed above. Therefore, teflon was selected as the wear surface material and the mechanical design was performed to add it to the endplate surface. The final design involved attaching a sheet of teflon material to the face of the endplate and then machining the teflon surface to a precise dimension. Adhesion of the teflon to the endplate was accomplished using a high temperature, high strength silicone adhesive.

During the performance testing of the compressor, which was described in Section 2.2.3, internal shims of

various thicknesses were used to adjust the build clearances between the rotor and endplate to different values to test the effects of that clearance upon the performance of the compressor. Those various shim thicknesses were selected over a range such that ultimately the rotor face did make contact with the teflon wear surface on one end of the machine. The teflon material worked perfectly in response to the contact with the rotor face and was determined to be a success in its ability to accomodate the rotor thermal growth.

As discussed in Section 3.2.6, a failure was experienced by the compressor during testing which involved the vane and rotor rubbing interface. As a consequence of that failure, at least one of the vanes made unexpected contact with the teflon material and caused severe wear in that surface. In addition to receiving deep scalloped gouges, the teflon material was actually pulled away from the endplate over a portion of its circumference. The failure of the teflon adhesion was determined to be a direct result of the primary vane/rotor failure and so a redesign of the teflon surface adhesion was not required. A convenient substitution was made however at that time by switching to a higher temperature capable adhesive of the same brand.

After the compressor was repaired and reassembled

further testing showed the teflon wear surface continued to perform adequately. Although additional testing is required, and life testing will be necessary, it is expected that the wear surface concept is a useful method of running clearance control.

3.2.4 Rotor/Endplate Running Clearances Effects

Previous performance analysis of Ecton's rotary vane machines revealed that the internal leakage that exists between the end of the rotor and the wall of the endplate contributes significantly to the internal losses of the machines. One important design goal then is to configure the rotor and endplate to properly account for the change in clearances from the build to the running condition such that the running clearance between the two is both controlled and minimized. Because of the build up of fabrication tolerances and because of the effects of thermal growth of the various machine components, the extent of the "control" of the running clearance has a significant tolerance. It is therefore not only important to know the expected nominal running clearance, but it is equally important that the variation in performance with the rotor to endplate clearance is known. Features were therefore incorporated into the compressor design to allow the build clearance between the rotor and endplate to be adjusted such that test data could be obtained over a range of that clearance. Prior to each test, the build

clearance would be adjusted by using a thicker or thinner shim within the machine and the resulting clearance noted for that test.

The testing of the compressor never attained the design speed of the machine and so design point testing of the influence of the rotor to endplate running clearance was not made. However, during the start-up and run-in testing of the compressor several disassemblies of the machine were required and at various times during those disassemblies the controlling shim dimensions were changed to decrease the running clearances in attempts to reach the design levels of efficiency. The results of changing the shim dimensions for a number of common test conditions were reported in Section 2.2.3. The data shows that as the build clearances were reduced the measured efficiences at the various running conditions improved.

The closest build clearances between the rotor and endplate were .002 and .0065 (reference Section 2.2.3).

3.2.5 Vane Tip Rubbing Adjustments

During the operation of the rotary vane machine many effects combined to determine the relative position of the vane tip to the stator housing wall. The clearance between those two components, called the vane tip clearance, represents a seal between the adjacent compression cavaties. The effectiveness of that seal, which will always leak to some degree, has

significant influence on the overall performance of the machine. It is therefore desirable to maintain a minimum clearance in that area while still avoiding metal-to-metal contact. The several parameters which influence that clearance include manufacturing tolerance, cam bearing internal clearance, retaining ring thermal growth, vane body thermal growth, vane body deflection, stator housing thermal growth, and stator housing deflection. During the analysis of those features and the subsequent design of the detail parts it was determined that very accurate and detailed analysis and design of each of those parameters was not within the scope of the program. It was therefore planned to design the parts with precise but nominal dimensions accounting only for the mechanical (e.g. internal bearing clearance) effects. It was therefore expected and planned that the vane tips would rub the stator housing at speeds below the design speed. It was planned to detect vane tip rubbing during testing and then to remove stock from the vane tips to increase the vane tip to stator housing clearance. The rework would be performed in increments until the design speed of the machine was attained.

The start-up and run-in testing was started on 13 May 1982. As the machine was increased in speed, vane tip rubbing was detected at 300, 2000, 2200, and 3000 rpm. At each of those speeds, except the last,

material was removed from either the vane tips, the stator wall, or both by grinding and testing was resumed. Testing was not performed at speeds over 3000 rpm.

Although the procedures of detecting vane tip rubbing and then correcting through material removal was successful in allowing increased speed operation with minimum vane tip rubbing, the time required for the disassembly, rework and reassembly was significant. For future designs attempts must be made at predicting the thermal growth effects on the vane tip clearance to reduce the amount of rework and time required at testing.

No attempts were made to measure the running vane tip clearance of the machine.

3.2.6 Vane/Rotor Rubbing Failure

The start-up and run-in testing of the compressor was performed during May and June of 1982. That testing consisted mainly of slowly increasing the compressor speed until vane tip rubbing was detected and then reworking either the vane tips or stator housing or both to allow higher speed testing (reference Section 3.2.5). Changes were also made in the shim adjustment which controls the rotor to endplate clearance in attempts to improve the measured efficiencies (reference Section 3.2.4).

As routine disassemblies of the compressor were

performed during the testing program, records were made of the inspected conditions of several of the machine's components. During the disassembly of the machine on 20 May, for the purpose of reworking vane tips because of vane tip rubbing, evidence was discovered of wear between the vane and rotor at the vane bushing stops on three vanes. Because the wear was not considered excessive and because it only appeared in three of the twelve slot areas, it was decided that additional running time was required to gain more information about the wear condition before any constructive change could be considered. During the disassembly the involved vane and rotor surfaces were stoned to insure that no scratches or burrs existed which might aggravate a wear problem.

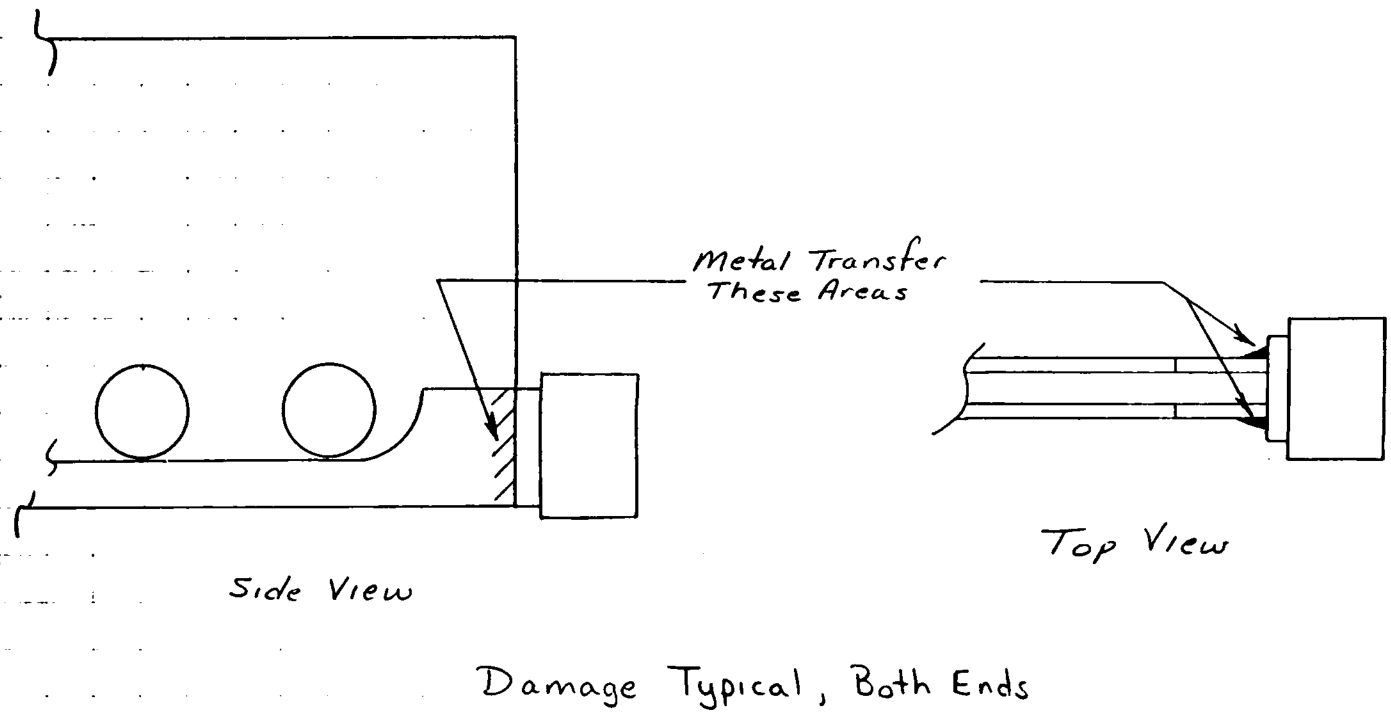
After reassembly of the machine the compressor test was restarted and the unit was operated at speeds up to 2200 rpm. At that speed vane tip rubbing was again detected and so the machine was disassembled for rework. At the time of that rework the vane and rotor slots were inspected for evidence of the wear observed in the previous disassembly but none was found. The compressor was reassembled and the test restarted with plans of running at speeds in excess of 2200 rpm. However, on 25 May 1982, during operation at 2000 rpm, the compressor rotor seized. The rotor would not then rotate in either direction. Upon disassembly of the

compressor it was found that the number 4 vane was locked between its two rotor segments at both ends of the machine. It became necessary to completely disassemble the rotor segments and shaft to break the vane away from the two segments. Upon removal of the rotor segments the vane easily separated from the segments.

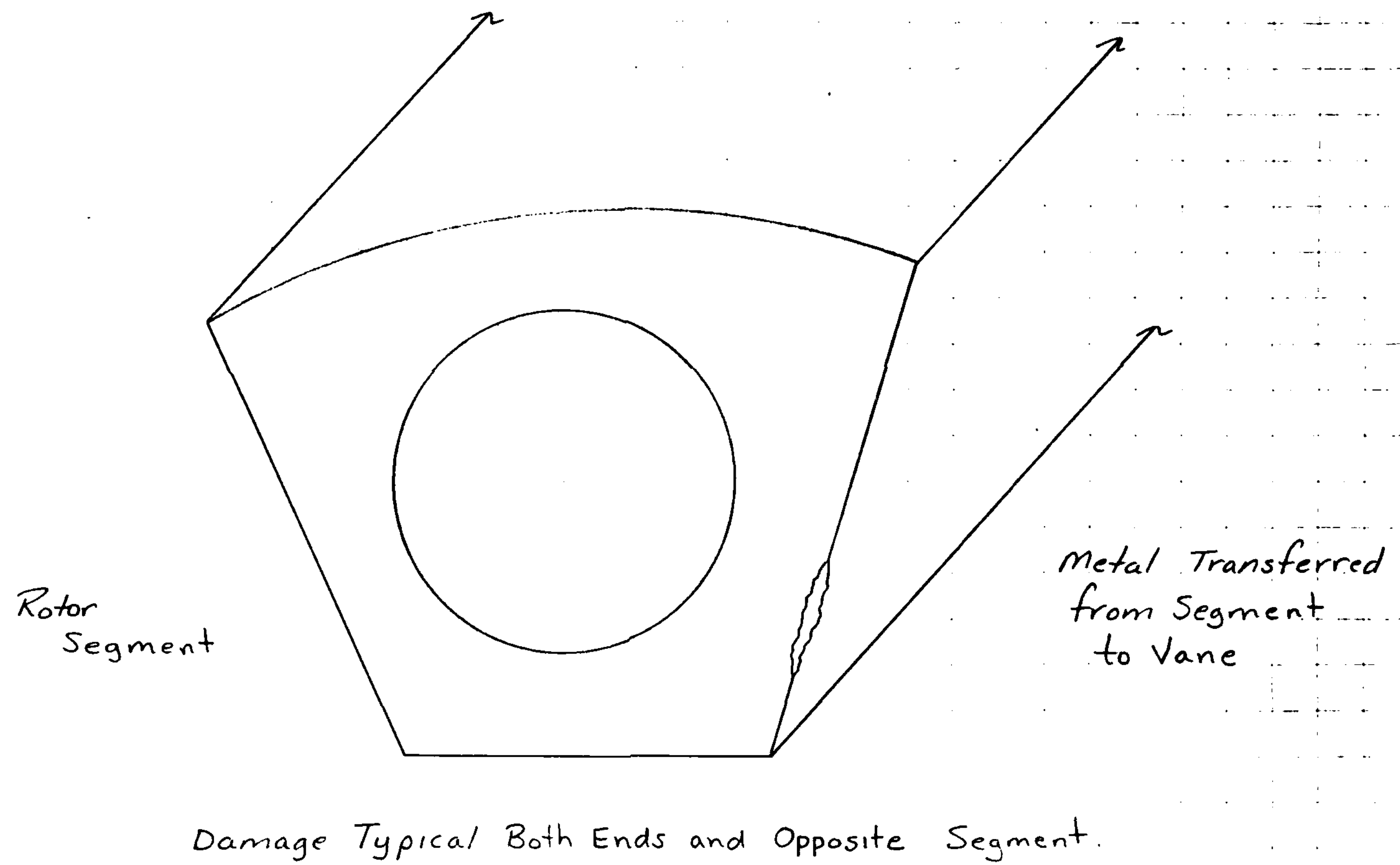
When the vane and rotor segments were separated, transfered metal adhered to the vane surfaces. A sketch of the damaged areas is shown in Figure 3.3. The damaged areas of the rotor segments are depicted in Figure 3.4.

The resulting depressions in the rotor segment surfaces were not filled but were carefully ground and stoned to remove any projecting material. In additon, the radius on the rotor segment at the intersection of the slot surface with the segment endface was ground and stoned by hand to increase the radius. The increased radius was expected to provide increased clearance between the rotor segment and the back side of the vane bushing stop.

The transferred metal was ground away from the vane and the original surface of the vane was regained. The surface was hand polished to remove any burrs. In addition, the back side of the vane bushing stop was radiused in the machine radial direction and then highly polished on that radius. That increased radius



Vane Transferred Metal, Sketch
Figure 3.3



Rotor Segment Damage, Sketch
Figure 3.4

was expected to better allow the vane to regain its normal position in the event that it is forced into a cocked position, for example as a result of vane tip rubbing and then rebounding.

Although the failure was confined to one end of one vane, all six vanes showed evidence of high temperature (burn marks) at two local points on one end (coinciding with the failure) of the vanes. The location of the burn marks coincided with expected rubbing areas of the vane with the teflon wear surface. At those same locations on the teflon wear surface, the teflon also showed signs of considerable wear. The teflon had actually separated from the endplate over a major portion of the circumference of the wear plate. On the opposite end of the machine no significant wear of the teflon was found and no burn marks existed on the vanes.

The transfer of metal from the rotor segment to the vane was an indication of extremely high temperatures at that interface. Those temperatures were probably due to excessive friction between the vane bushing stop and the rotor endface. Two possible occurrences would cause high friction in that area. If the vane became cocked in the slot then the bushing stops would rub the rotor endfaces. Also if the thermal growth of the rotor segment exceeded that of the vane then contact would be made between the rotor

and bushing stop. During design, fabrication, and assembly, great care was taken to insure that the clearance between the bushing stop and rotor face was tightly controlled and uniform for all bushings. Because the failure was not common to all bushing stops and because the thermal growth of the vane is expected to exceed that of the rotor, it is expected that the primary failure was not due to a closing of the running clearance as a result of thermal growth. (The vane has lower mass than the rotor segment and, being subjected to similar conditions, is expected to run at a higher temperature, especially considering the fact that the point of heat generation is constant for the vane but variable for the rotor. Also, the vane material has a higher coefficient of thermal expansion.)

The burn marks on the end of the vanes were probably due to high rubbing friction between those vane ends and the teflon wear surface. The burn marks were an obvious indication that the vane body temperature was increased in that area. As the vane body temperature increased, its length due to thermal expansion increased causing even more rubbing to take place. That is an unstable failure mode. It was believed that the contact of the vane with the wear surface caused the vanes to become cocked relative to the normal vane position and this caused local rubbing between the bushing stop and rotor endfaces. As the

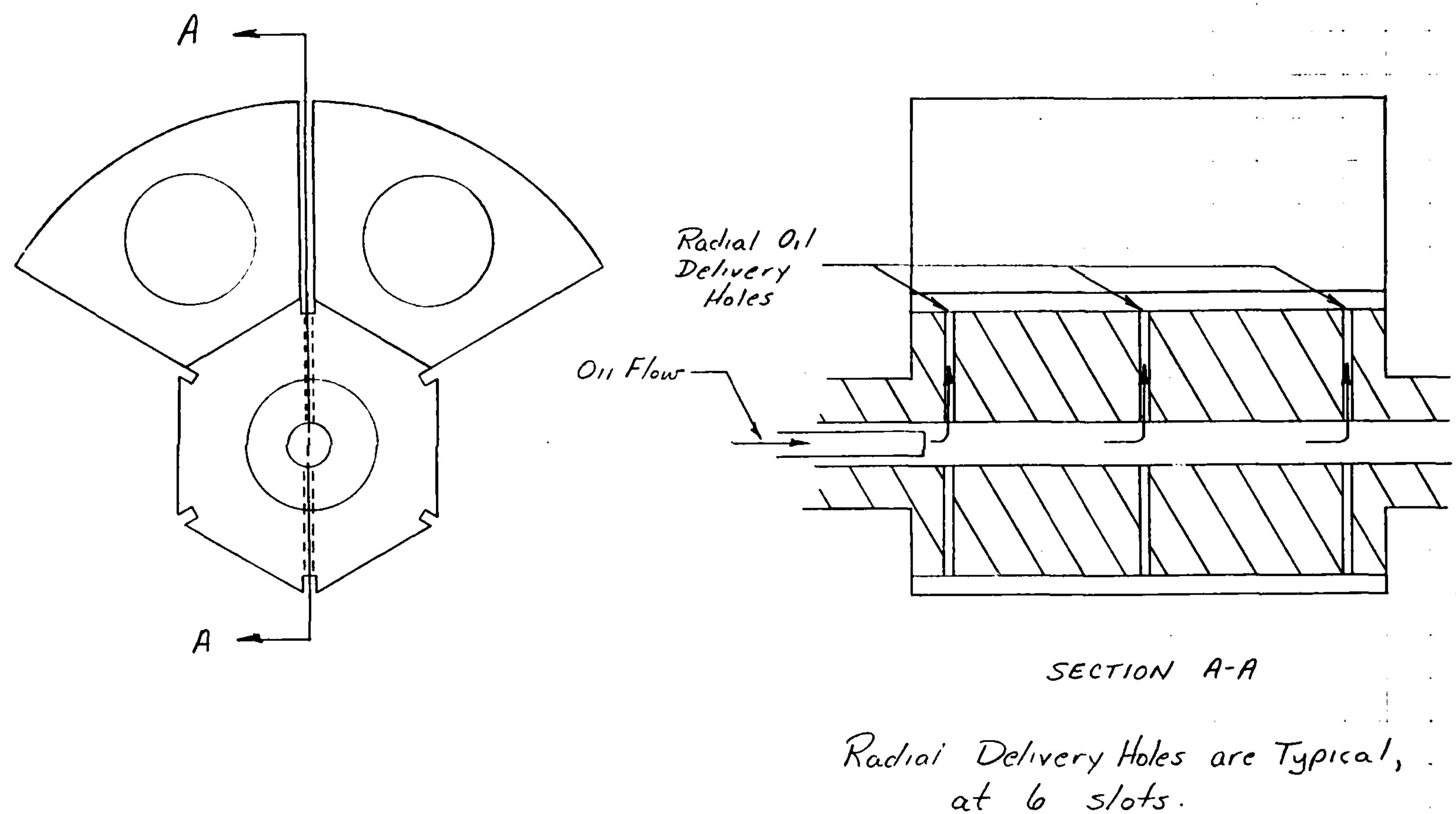
problem worsened the local condition of high friction at the bushing stop exceeded the ability of the lubricant to protect the two components and so the severe wear occurred. The fact that only one vane experienced severe wear could be due to differences in the surface finishes of the bushing stops or rotor endfaces, differences in the radii of the back side of the bushing stop or the rotor segment, or it could be a result of some unknown dynamic condition within the machine. For example, the frequency and force with which the vanes were pushed into a cocked position by the teflon surface (which was pulling away from the endplate) may have varied from vane to vane causing one vane to be more damaged than the others.

To prevent excessive contact between the vane and teflon surface it was planned that careful control of the build clearances, through selection of the internal shims, be maintained and that incremental reductions in that clearance be small during the efficiency improvement testing to provide early detection of a recurrence of the problem. To improve the clearance between the bushing stop and the rotor segment the radius on both the rotor segment and the back side of the bushing stop were increased and the surfaces were highly polished.

The original method of providing lubrication to the vane bushing stop and rotor slot area was by means

of migration of oil which was originally injected to the cam bearing. At several times during the testing, migration of that oil was observed through a window, which had been designed into one endplate, by using a strobe light to isolate bushing motion. During those observations it was obvious that the oil was moving from the cam bearing to the bushings then to the cam ring. The back side of the bushing stop could not be observed through the window to insure that oil was being delivered to that area. During all disassemblies of the machine however both the vane and rotor surfaces within the slot areas were found to be oil wetted. To insure that oil would be delivered to the area of the slot and bushing stop it was decided to deliver oil down the center of the shaft and to then allow it to be ejected radially into the rotor slots through holes drilled into the shaft. The shaft was reworked to include three radial holes per slot, with one hole near the middle and one hole near the ends of each slot. The revised oil delivery system is shown in Figure 3.5. The compressor end cap was modified to accept a fitting through which was passed a straight tube which then projected down the shaft centerline. During operation oil was delivered through that tube to the shaft.

New teflon wear surfaces were made and they were applied to the endplates using a higher temperature version of the original adhesive. The vane tips were



Shaft Centerline Oil Delivery Geometry

Figure 3.5

hand polished to remove scratches and burrs and the stator housing inside surface was hand polished. The compressor was then reassembled and testing continued on 1 June 1982.

After subsequent testing to speeds of 3000 rpm, the compressor was disassembled and inspected on at least seven occasions. No evidence of wear was ever found in the area of the vane bushing stop and rotor segment and those surfaces were always found to be oil wetted.

3.2.7 Retaining Ring Discoloration

The compressor testing performed during June 1982 consisted of operating the compressor at various speeds in attempts to get both speed and efficiencies up to the levels of the design conditions. After numerous disassemblies, inspections and rework of both the vanes and the stator housing, the compressor speed was increased to 3000 rpm on 18 June 1982. At that time vane tip rubbing was again detected and so testing was stopped to perform another tear down inspection and vane rework. Upon inspection of the machine, both retaining rings were found to be discolored from their original condition. The color was reported as a blue/purple near the inside diameter of the rings and varying to a straw color near the outside diameter. For both rings, the side facing the rotor was darker and more discolored than the side facing the endplate.

The inside diameter of both rings showed no evidence of adnormal wear, seemed highly polished, and no metal transfer was found on the rings or bushings. All twelve bushings were found to be in good condition with no signs of excessive wear. However, bushing #8 had rotated from its original position relative to the vane. A few vane axles also showed signs of excessive heat in the form of straw color discoloration. All bushing stop areas were in good condition with no severe wear indicated and no material transfer found.

As the retaining rings grew thermally in response to the high temperature, which is evidenced by the discoloration, the position of the vane tips would obviously approach the stator housing. Ultimately that growth would allow the vane tips to rub against the stator housing and rubbing was detected at 3000 rpm.

Because no excessive wear evidence was found, but yet the retaining rings were subjected to high temperature, it is believed that the lubrication provided to the retaining ring was adequate to prevent wear but inadequate to provide sufficient cooling for the retaining ring. One possible solution to that problem would be to deliver oil directly to the retaining ring by either an oil jet or oil mist. Plans to add such a scheme of lubrication were made but were never implemented because testing on the compressor was stopped on 21 June 1982. Such a scheme of oil delivery

would be mechanically simple and easy to design into the compressor. Before the compressor is again operated at speeds over 2500 rpm such a system must be installed.

It is expected that a more significant design change could allow for better internal distribution of the oil thus avoiding the use of multiple oil delivery configurations. Such improvements should be made in future developments of the compressor.

3.3 Instrumentation and Test Apparatus

3.3.1 Expander Test Instrumentation

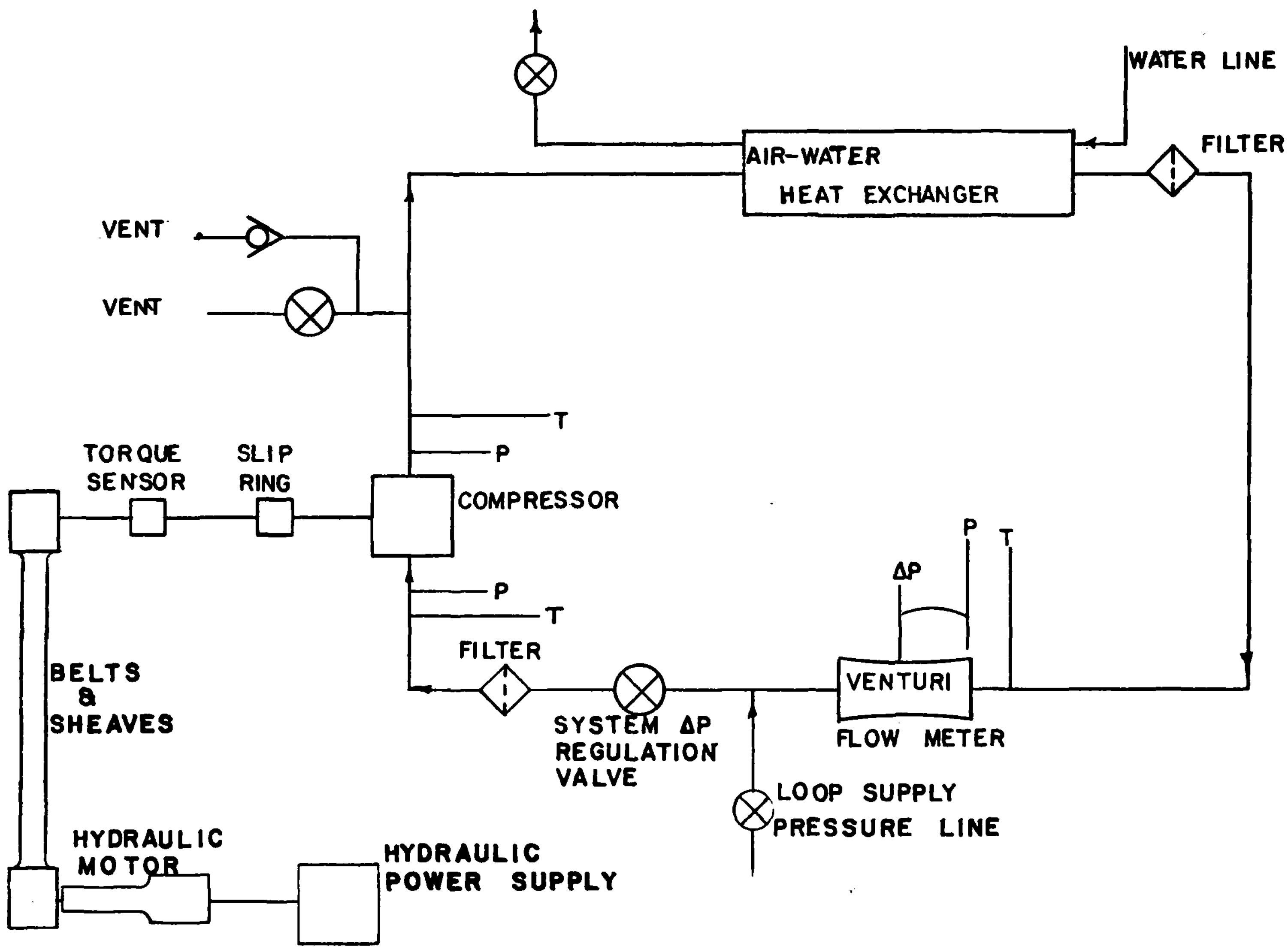
The instrumentation used on the expander was the same as that described in Section 2-E of the Interim Report (Reference 1). However, because of the early mechanical failure, no data was taken during the short test reported in Section 3.1.1 of this report. Also, no test data was taken during the final run-up, to 2800 rpm, made after the final assembly and before shipment to MERADCOM.

3.3.2 Compressor Test Instrumentation

A schematic of the compressor test rig system is shown in Figure 3.6. (That figure is identical to Figure 2.7, and is repeated here for convenience.) A closed loop test rig arrangement was used. The necessary features of filtration, pressure regulation, heat rejection, oil separation and speed control were included. The instrumentation was connected to Ecton's

Figure 3.6

COMPRESSOR TEST RIG SYSTEM



Automatic Data Aquisition System (ADAS) and certain redunant instrumentation was provided for direct visual readout. All data kept for record and used to determine the performance of the compressor was monitored and stored by the ADAS. At selected times (refer to Section 2.2.3) the instrumented paramenters were both printed on paper by the ADAS and stored on the computer diskettes.

The list of instrumented parameters is given in Table 3.2. That list provides the description, ADAS variable name, units and type of instrumentation used. Calibration of most of the instrumentation was not performed before the testing reported in this document because that testing was planned to be the run-up portion. The plan was to calibrate the instrumentation after the run-up testing was completed and before the performance testing was started. However, because of schedule delays and mechanical problems with the compressor, the performance testing was not done. Calibrations were therefore performed after the run-up testing and reported here as post test calibrations.

Two rotor segment metal temperature thermocouples were installed. Their output, identified as TROT1 and TROT2, was erratic during the run-up testing and so their values were not used.

Calibration sheets for the four pressure transducers are given in Tables 3.3 through 3.6. Those

Table 3.2

Compressor Rig Instrumentation List

Description	ADAS Name	Units	Instrumentation Type
Inlet Pressure	PEI	Psia	Strain gage pressure transducer
Outlet Pressure	PEO	Psia	Strain gage pressure transducer
Venturi Inlet Pressure	PO	Psia	Strain gage pressure transducer
Venturi Pressure Drop	DELP	Psid	Strain gage pressure transducer
Inlet Temperature	TEI	F	Copper-constantan thermocouple
Outlet Temperature	TEO	F	Copper-constantan thermocouple
Venturi Inlet Temperature	TO	F	Copper-constantan thermocouple
Shaft Speed	RPM	rpm	Toothed gear and magnetic pickup
Shaft Torque	TORQ	ft-lbf	Lebow strain gage torque sensor
Rotor Segment Temp.	TROTI	F	Copper-constantan thermocouple
Rotor Segment Temp.	TROT2	F	Copper-constantan thermocouple
Endplate Surface Temp.	THUB	F	Copper-constantan thermocouple
Oil Flow Rates (3)	--	Unit	Modified float type rotameter

Table 3.3

0-10 Psid Pressure Transducer Calibration

ACCEPTED ☐
REJECTED ☐

~~SERIAL~~ MOD NO. 1396-02

SERIAL NO. 59167

SHEET NO. ____ OF ____

S. O. NO. ________

PART NAME 1396-02 0-10 PSID DIFFERENTIAL PRESSURE TRANSDUCER

PART NO. 1396-02

REVISION ________

DATE 16 July 82

INSPECTION NO. / PRINT DIM.	IN Hg NO. 1	DAS NO. 2	AV NO. 3	P/S NO. 4	PSID TRUE NO. 5	DEV % FS NO. 6 OF FULL SC
	20.46	10.01	-29.546	10.007	9.996	+.190
	18.34	8.98	-26.499	10.006	8.960	+.2
	15.58	7.65	-22.566	10.007	7.611	+.4
	14.12	6.94	-20.461	10.007	6.898	+.4
	11.78	5.80	-17.077	10.007	5.755	+.5
	10.20	5.03	-14.805	10.007	4.983	+.5
	7.73	3.82	-11.198	10.007	3.776	+.4
	3.67	1.82	-5.270	10.007	1.793	+.3
	2.03	1.01	-2.891	10.007	.992	+.2
	.78	.38	-1.003	10.007	.381	.00
	0	.00	+.111	10.007	0	.00
Temp = 85°F						
IN Hg * .48854						
SURF. FIN. SPEC.						
HARDNESS SPEC.						

INSPECTED BY ________ DATE ________

Table 3.4
0-25 Psia Pressure Transducer Calibration

ACCEPTED ☐
REJECTED ☐

SERIAL NO. TJE/-713

SERIAL NO. 47253

SHEET NO. ____ OF ___

S. O. NO. ______

PART NAME 0-25 PSIA PRESSURE TRANSDUCER

PART NO. TJE/713
REVISION Revision to (47253) (7/16/82)
DATE July 27, 1982

NEW AX+B → DAS(PSIA) = .8268(mV) + .6682

INSPECTION NO.	IN Hg	NEW DAS	mV		PSIA	DAS in % of
PRINT DIM.	NO. 1	NO. 2	NO. 3	NO. 4	NO. 5	NO. 6
		VALUES				full scale
						% of reading
	21.85			10.002	25.06	
	19.29			10.002	23.80	↓
	11.48	19.93	23.301	10.002	19.99	-.2 -.3
	22.50	25.33	29.831	.002	25.33	.0 .0
	17.74	23.01	27.022	.003	23.00	.0 .0
	14.48	21.39	25.061	.003	21.41	-.1 -.1
	9.78	19.11	22.308	.003	19.11	.0 .0
	5.91	17.22	20.024	.003	17.22	.0 .0
	2.89	15.75	18.241	.004	15.74	.0 +.1
	0	14.34	16.530	.004	14.33	.0 +.1
July 28, 1982 atmospheric pressure (29.11-.018) in Hg (at 0930) * .48918 psi/in Hg = 14.23						
mercury (IN Hg) at 72°F	-.48918					
	0	14.22	16.389	10.000	14.23	
mercury at 81°F .48869	.68→.33	14.55	16.795	10.001	14.56	
	5.36→2.62	16.83	19.552	10.001	16.85	
	7.49→3.66	17.88	20.817	10.002	17.89	
	10.56→5.16	19.37	22.624	10.002	19.39	
	14.02→6.85	21.08	24.689	10.002	21.08	
	16.62→8.12	22.36	26.236	10.002	22.35	
	20.3→9.92	24.13	28.382	10.002	24.15	
X	22.07→10.79	24.19	28.461	10.002	25.02	
X	20.89→10.21	24.22	28.495	10.003	24.94	
	19.19→9.39	23.60	27.743	10.002	23.61	
X	20.79→10.16	24.11	28.237	10.003	24.39	
X	20.18→9.86	24.00	28.226	10.003	24.09	
X	20.54→10.0	24.15	28.410	10.003	24.27	
	18.84→9.21	23.44	27.553	10.003	23.44	
	13.95→6.82	21.04	24.653	10.003	21.05	
	8.21→4.01	18.26	21.281	10.003	18.24	
	0	14.24	2	10.004	14.23	
SURF. FIN. SPEC.						
HARDNESS SPEC.						

INSPECTED BY __________ DATE ______

Table 3.5

0-75 Psia Pressure Transducer Calibration

ACCEPTED ☒
REJECTED ☐

SERIAL NO. ____

SERIAL NO. 47220

SHEET NO. ____ OF ____

S. O. NO. ____

PART NAME 0-75 PSIA

PART NO. TJE/713

REVISION ____

START AT 1500

DATE July 15, 1982

ABSOLUTE PRESSURE 29.28 = 14.32

INSPECTION NO.	DEADWEIGHT	DAS	mV	P/S	ABSOLUTE P	DEVIATION
PRINT DIM.	NO. 1	NO. 2	NO. 3	NO. 4	NO. 5	NO. 6 % OF FULL SCALE
dev in % of full scale						
.11	0	14.18	5.743	10.010	14.04	+.2
.16	15	28.98	11.669	.010	29.04	-.08
.00	25	39.08	15.714	.010	39.04	+.05
.16	35	48.98	19.677	.010	49.04	-.08
.11	45	59.02	23.697	.010	59.04	-.03
.09	55	69.07	27.721	.010	69.04	+.04
.03	60	74.08	29.727	.010	74.09	+.05
.00	60	74.10	29.736	.010	74.09	+.08
.05	55	69.06	27.716	.010	69.04	+.03
.05	45	59.06	23.714	.010	59.04	+.03
.01	35	48.99	19.679	.010	49.04	-.07
.09	25	38.97	15.670	.010	39.04	-.09
.09	15	28.97	11.666	10.010	29.04	-.09

@ 72°F
INHG * .48918 = PSI

266

oil column = 9"
specific gravity of hydraulic oil = .864
.0361 * .864 * 9" = .28 PSI = OIL COLUMN

ABSOLUTE PRESSURE = ATMOSPHERIC PRESSURE + DEADWEIGHTS − OIL COLUMN

SURF. FIN. SPEC.
HARDNESS SPEC.

INSPECTED BY ____ DATE ____

Table 3.6

0-150 Psia Pressure Transducer Calibration

ACCEPTED ☐
REJECTED ☐

~~SERIAL~~ MODEL NO. TJE/713

SERIAL NO. 46755

SHEET NO.____OF___

S. O. NO.________

PART NAME 0-150 PSIA PRESSURE TRANSDUCER

PART NO. TJE/713

REVISION

START 1206 ATMOSPHERIC PRESS DATE July 15 1982

PEI 14.17 29.31 IN HG = 14.34

INSPECTION NO.	DEADWEIGHTS	DAS	MV	P/S	ABSOLUTE PRESSURE	DEVIATION
PRINT DIM.	NO. 1	NO. 2	NO. 3	NO. 4	NO. 5	NO. 6 %
(GAGE) NOMINAL PRESS.						of reading
				dev in %	of full scale	
	0	14.24	2.786	10.009	14.34	−.7 .07
	5	19.26	3.793	.008	19.06	+1.1 .13
	10	29.29	4.801	.008	24.06	+.9 .16
	20	34.18	6.784	.009	34.06	+.35 .08
	30	44.00	8.752	.009	44.06	−.14 .04
	40	54.01	10.758	.009	54.06	−.09 .03
	50	64.08	12.775	.008	64.06	+.03 .02
	60	74.03	14.770	.008	74.06	−.04 .02
	70	84.04	16.776	.008	84.06	.02 .01
	80	94.06	18.785	.008	94.06	.00 .00
	90	104.08	20.790	.008	104.06	+.02 .01
	100	114.00	22.780	.008	114.06	−.05 .04
	110	124.06	24.797	.008	124.06	.00 .00
	120	134.07	26.880	.008	134.06	+.01 .01
	130	144.09	28.808	.008	144.06	+.02 .02
	135	149.16	29.829	.007	149.06	+.07 .07
	125	139.13	27.815	.007	139.06	+.05 .05
	115	129.12	25.812	.008	129.06	+.05 .04
	105	119.12	23.807	.008	119.06	+.05 .04
	110	124.08	24.802	.008	124.06	+.02 .01
	100	119.12	22.805	.008	114.06	+.05 .04
	90	104.11	20.798	.008	109.06	.05 .02
	80	94.10	18.792	.008	94.06	.04 .03
	70	84.09	16.786	.008	84.06	.04 .02
	60	74.05	14.776	.008	74.06	.01 .01
	50	64.08	12.776	.008	64.06	.03 .01
ABSOLUTE PRESSURE =	40	59.02	10.760	.008	54.06	.07 .03
DEAD WEIGHTS + ATMOS	30	44.02	8.755	.008	44.06	.09 .03
− OIL COLUMN	20	34.16	6.780	.008	34.06	.29 .07
	10	24.04	4.750	.008	24.06	.08 .01
	15	28.99	5.743	.008	29.06	.24 .05
	0	14.15	2.769	.008	14.06	.64 .06
IN Hg * .49115 = psi						
OIL COLUMN = 9"	SP Gr oil .864 9" * .0361 * .864 = .28 PSI					
SURF. FIN. SPEC.						
HARDNESS SPEC.						

INSPECTED BY Robin A. David DATE________

calibrations were performed in-house using a mercury monometer as the testing standard. The monometer used was a Meriam instrument model 310EC10WM. Corrections were made to the monometer reading for altitude and ambient temperature affects. The temperature correction was obtained from the Meriam Instrument Company.

The torque sensor used to measure the input torque to the compressor was also calibrated in house. A balance beam was attached to the shaft of the torque sensor and then certified weights were placed on the bar at a precise radius from the shaft center line and the output torque reading of the torque sensor was documented. Comparison of the torque sensor output to the known applied torque yielded an equation for the true torque as a function of the millivolt output of the sensor. The data generated in the calibration and the resulting equation and accuracies are listed in Table 3.7.

The venturi flow meter was calibrated by Flow-Dyne Engineering Incorporated. Their certificate of calibration is shown in Table 3.8 and the calibration data is listed in Table 3.9. Their curve of flow parameter versus pressure ratio is shown in Figure 3.7. As shown by the data reduction equations of Appendix E the equation used to calculate the venturi flow rate was the general equation which accounts for the various

Table 3.7

Torque Sensor Calibration

ACCEPTED ☒
REJECTED ☐

SERIAL NO. ______

SERIAL NO. 1612

SHEET NO. 1 OF 1

S. O. NO. ______

PART NAME 0-500 in.lb. torque sensor, LEBOW

PART NO. ______
REVISION ______
DATE July 27, 1982

Ft.LB. = -1.988 MV + (-.2903)

INSPECTION NO.		NEW BX+B				
PRINT DIM.	NO. 1	NO. 2 DAS	NO. 3	NO. 4	NO. 5	NO. 6
	Actual Torque (ft-lbf)	Indicated Torque (ft-lbf)	Millivolt Reading (mVDC)	Excitation Voltage (VDC)		% %
	0	.002	-.145	10.001		.00 ~
	4.997	5.006	-2.664	10.002		.02 .2
	12.49	12.42	-6.391	10.001	/	.17 .6
	6.246	6.203	-3.266	10.002		.10 .69
	34.980	34.979	-17.741	10.009		.00 .00
	0	.000	-.146	10.002		.00
	4.997	4.992	-2.657	9.999		.01 .1
	.6426	.625	-.460	9.994		.04 2.7
	9.994	9.993	-5.173	10.001		.00 .01
	17.489	17.467	-8.934	10.002		.05 .13
	22.486	22.485	-11.460	10.003		.00 .0[illegible]
	27.483	27.473	-13.971	10.004		.02 .04
	32.479	32.493	-16.497	10.004		.02 .04
SURF. FIN. SPEC.						
HARDNESS SPEC.						

INSPECTED BY ______ DATE ______

FLOW-DYNE *Engineering, Inc.*

FLOWMETERS—Liquid—Gaseous—Cryogenic

P. O. Box 9034 • Fort Worth, Texas 76107

Telephone: (817) 732-2858

CERTIFICATE
OF
CALIBRATION

This is to certify that VENTURI FLOWMETER

Part Number V200800-SPT Serial Number 19591

on Purchase Order 7504 dated 14 AUG 80

for ECTON CORP. DAYTON, OHIO

was calibrated with AIR using National Bureau of Standards (NBS) traceable equipment. The accuracy tolerance is ± 0.50%.

Reference Flow-Dyne Sales Order 1959-80.

RICHARD C. CONN
CHIEF ENGINEER

Table 3.8

AD-A130 976 DEVELOPMENT OF A HIGH EFFICIENCY COMPRESSOR/EXPANDER FOR AN AIR CYCLE AIR CONDITIONING SYSTEM(U) ECTON CORP DAYTON OH R L SUMMERS ET AL. 15 NOV 82 2/2

UNCLASSIFIED DAAK70-79-C-0042 F/G 13/1 NL

END

FILMED

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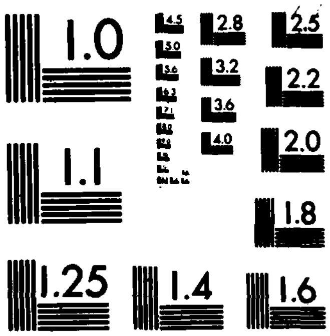


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Table 3.9

CEESI

COLORADO ENGINEERING EXPERIMENT STATION INC.

OFFICE:
P.O. Box 344
Boulder, Colo. 80302

LABORATORY:
P.O. Box 41
Nunn, Colo. 80648
Phone: 303—897-2340

CALIBRATIØN ØF A SUB-SØNIC NØZZLE
MØDEL: V200800 SERIAL NUMBER: 19591
FØR: FLØW-DYNE ENGINEERING, INC. ØRDER: 0720-80
DATA FILE: 80FDE29 DATE: 10-21-80
INLET DIA: 1.364 INCHES THRØAT DIA: 0.8 INCHES
TEST GAS: AIR STD DENSITY= 0.074916 LBM/CU-FT
AT STANDARD CØNDITIØNS ØF 529.69 DEG R, AND 14.696 PSIA
K=CØEF ØF DISCHARGE, VELØCITY ØF APPRØACH FACTØR NØT INCLUDED
ACFM: FLØWRATE IN ACTUAL CUBIC FEET PER MINUTE
MTR READ: INCHES ØF WATER DIFF PRESSURE @ 4 DEG C
REY NØ: THRØAT REYNØLDS NUMBER
RATIØ ØF SPECIFIC HEATS: 1.4
FØR EXP FAC, SEE ASME FLUID METERS 6TH P.220

L	MTR READ	ACFM	K FACTØR	REY NØ	LBM/SEC
1	79.903	80.251	0.99906	391120.	0.24784
2	60.299	70.568	0.99809	344040.	0.21798
3	79.443	79.788	0.99794	390930.	0.24754
4	77.436	78.718	0.99794	388210.	0.24527
5	58.641	69.391	0.99724	341460.	0.21573
6	43.502	60.056	0.99263	295370.	0.18695
7	30.709	50.825	0.99002	249240.	0.15771
8	43.422	59.995	0.99256	295330.	0.18678
9	20.063	41.24	0.98761	202650.	0.12811
10	11.954	31.945	0.98583	156920.	0.099216
11	19.993	41.182	0.98815	202480.	0.128
12	6.112	22.749	0.9781	111700.	0.070647
13	7.979	26.12	0.98329	127900.	0.080984
14	6.142	22.886	0.98056	111990.	0.070922
15	4.764	20.131	0.97813	98419.	0.062338
16	6.132	22.882	0.98127	111950.	0.070922
17	3.565	17.377	0.9755	84967.	0.053834
18	2.537	14.625	0.97287	71551.	0.045333
19	3.565	17.386	0.97563	84943.	0.053818
20	1.698	11.904	0.96697	58173.	0.036863
21	1.019	9.1863	0.96245	44850.	0.028425
22	1.678	11.887	0.97184	58148.	0.036852
23	0.519	6.4683	0.94919	31570.	0.020011
24	0.28	4.6717	0.93246	22762.	0.01443
25	0.509	6.4492	0.95686	31553.	0.020003
26	9.437	28.428	0.98526	139330.	0.088197

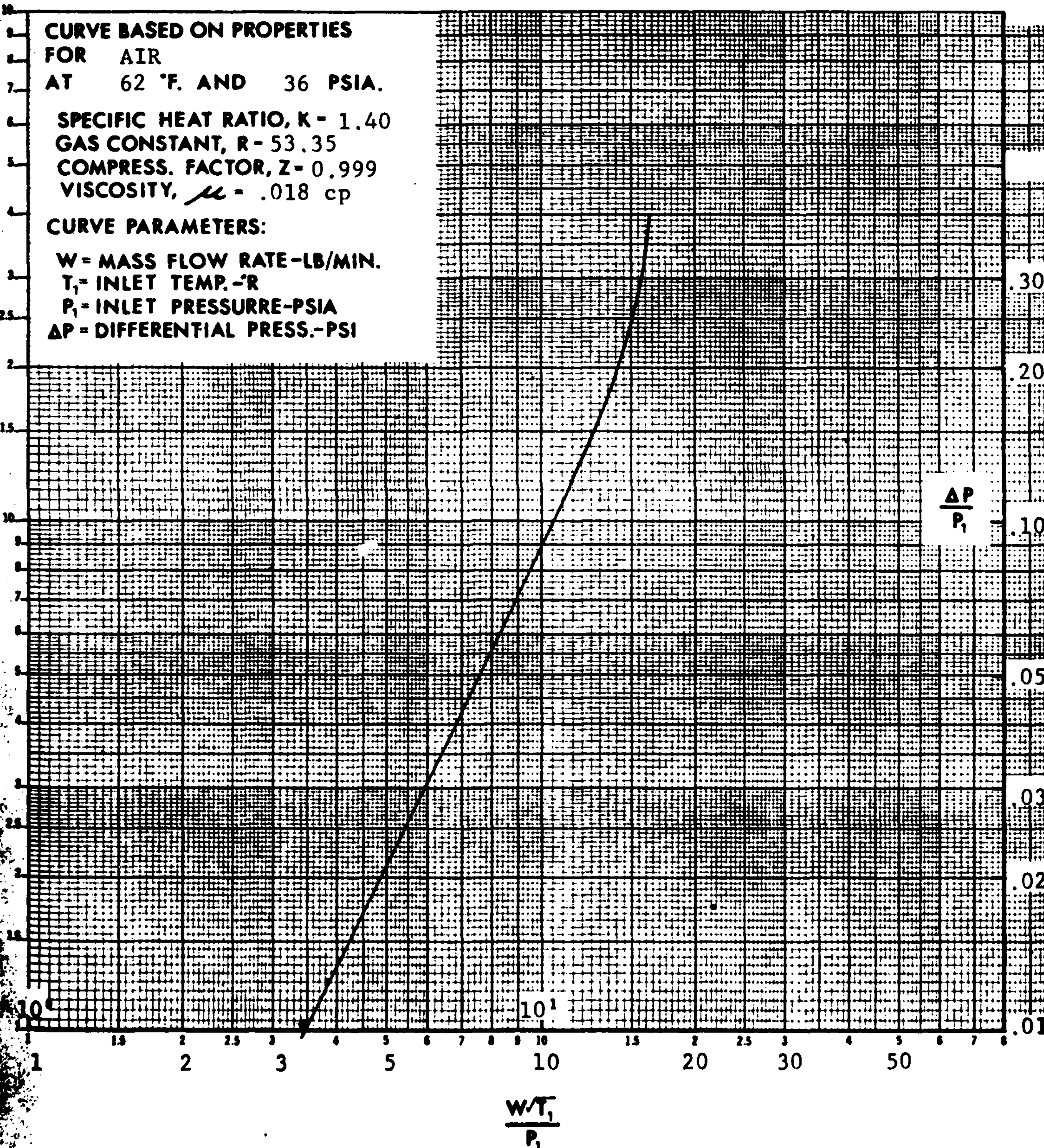
AVERAGE VALUES FØR ABØVE RESULTS:
P= 35.975 PSIA DENSITY= 0.18606 LBM/CU-FT
T= 522.41 DEG R VISCØSITY= 1.0077E-6 LBM/INCH-SEC
Z= 0.99902 CØMPRESSIBILITY FACTØR

FLOW-DYNE *Engineering, Inc.*
FLOWMETERS—Liquid—Gaseous—Cryogenic
P.O. BOX 9034
FORT WORTH, TEXAS 76107
(817) 732-2859

Figure 3.7

VENTURI P/N: V200800-SPT
S/N: 19591
THROAT DIA: 0.800"
LINE SIZE: 1¼" SCH 40 PIPE
LENGTH: 10"

VENTURI PERFORMANCE CURVE
FOR AIR



characteristics (for example, compressability, velocity of approach, and coefficient of discharge). That equation was not replaced by the Venturi flow meter calibration curve because the testing never progressed to the point of performance testing. For the period of the preliminary run-up testing the generalized equation was used and the coefficient of discharge of .984 was used because it was the average discharge coefficient determined by the calibration. Time was not available for reduction of the test data using the equation of the flow calibration but sufficient test data is provided in this report to allow that update to be made.

4. CONCLUSIONS

The following conclusions are listed approximately in order of decreasing significance.

1) Limited analytical predictions of the effects of all parameters on vane, endplate and stator deflections and thermal growth should be attempted for new designs to reduce the run-up time required during testing.

2) The vane bushing stop and rotor segment interface geometry must be accurately dimensioned and the surfaces polished.

3) Oil delivery systems for specific rubbing pairs should be designed for positive delivery.

4) Rotor to endplate running clearances should be smaller than .002 inches.

5) Design features should be added which allow for easier and quicker machine assembly and disassembly.

6) Wear plates are useful for clearance control.

7) The significant retaining ring radial growth might be avoided by using an outer (relative to the vane bushing) cam bearing configuration.

8) Estimates of oil quantity required for cooling the rubbing interfaces is needed.

9) Highly efficient oil separation is difficult to achieve without extensive design and special apparatus.

10) Shaft centerline oil delivery may be adequate for the vane bushing stop and rotor segment interface.

11) The use of low expansion materials should be considered for the various machine components.

12) Vane axles which stand up to abuse such as interference with the stator, even to the point of rotor seizure, can be designed.

13) Continuous monitoring of vibration would be useful.

14) Detection of vane tip rubbing by audible sound is difficult.

15) When using an Automatic Data Acquistion System, test results should be plotted automatically to immediately judge the quality of the data.

16) Methods to reduce the compression and expansion generated noise should be investigated.

17) Instrumentation calibrations should be performed before any testing is started.

5. RECOMMENDATIONS

1) The expander should be subjected to long term testing.

2) The expander should be tested at the design point condition with oils of various viscosities to determine if an optimum viscosity can be found.

3) The compressor design should be revised to provide better lubrication to the vane bushing/retaining ring and the vane bushing stop/rotor segment interfaces. The revised design should also provide better oil flow for cooling of the retaining ring.

4) Further testing of the compressor should be limited to 2800 rpm if no design change is made to provide better cooling of the retaining ring.

5) Compressor design revisions, to limit further radial movement of the vane tips, should be implemented and the compressor run up to a speed of 3450 rpm.

6) Design point testing of the compressor should be performed over a range of rotor to endplate clearances to better determine the influence of that clearance and to identify an appropriate build clearance value.

7) A compressor design revision to change the cam bearing to an outer (relative to the vane bushing) cam bearing configuration should be considered.

8) The vane bushing stop to rotor segment interface

geometry should be reviewed to determine if better sliding conditions can be attained.

9) The compressor and expander should be connected in an appropriate closed loop test rig and run to obtain performance data.

10) To expedite the development, the expander and compressor should be used as test articles, to evaluate any proposed performance improvement techniques, as opposed to total fabrication of new designs.

11) The compressor and expander designs should be changed to replace the current shims with metal shims.

12) The data reduction equations (reference Appendix E) should be revised to include the actual flowmeter calibration curve and the test data should be reduced again to obtain corrected values.

13) An analysis should be performed to estimate the improvement in clearance control obtained by using low expansion materials for various components.

REFERENCES

1) Report DAAK70-79-C-0042, "Development of a High Efficiency Compressor/Expander for an Air Cycle Air Conditioning System", Interim Report, by Ronald E. Smolinski, Ecton Corporation.

2) Metals Handbook, 9th Ed., Vols 1, 2, & 3, American Society of Metals.

3) Shigley, Joseph Edward, Mechanical Engineering Design, 3rd Ed., McGraw Hill, New York.

4) Spotts, M.F., Design of Machine Elements, 5th Ed., Prentice Hall, Englewood Cliffs, New Jersey.

Appendix A

UDRI Expander Vane Axle Failure Analysis Report

UNIVERSITY OF DAYTON
DAYTON, OHIO 45469

RESEARCH INSTITUTE

May 20, 1981

Mr. Robin David
Ecton Corporation
5863 Webster St.
Dayton, OH 45414

Dear Robin,

I have attached two copies of our report concerning our examination of the compressor vane-axle failure and our evaluation of the new vanes. As we discussed in earlier telephone conversations, the cause of the failure you observed in your bench tests was the result of a defective aluminum casting. Numerous shrinkage cavities were present in the fractured surface thus giving rise to unpredictably high shear stresses in the axle-vane transition region.

Our examination of the retaining ring showed essentially no aluminum present, indicating little aluminum was lost from the fracture and loose, running around in the compressor following failure.

The mechanical test data speaks for itself.

Should you have any question regarding either the report or the tests, please feel free to call on me.

Sincerely,

Dick Harmer

Richard S. Harmer

RSH/skl

Enclosures

ANALYSIS OF VANE AXLE FAILURES

SUMMARY OF RESULTS

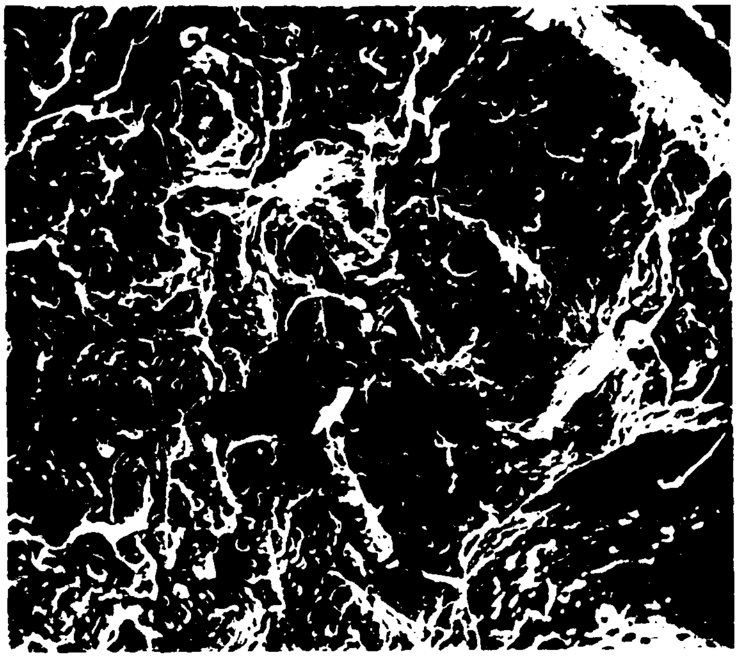
Examination of the vane with a broken axle supplied by Ecton Corporation showed it contained many shrinkage pores resulting from poor casting practice. The failure was the result of normal loading of a cross-sectional area substantially smaller than was thought to exist owing to the presence of the shrinkage cavities.

Examination of the retaining ring showed little, if any, aluminum present on the wear surface of the retaining ring. The quantity of aluminum was only at a trace level.

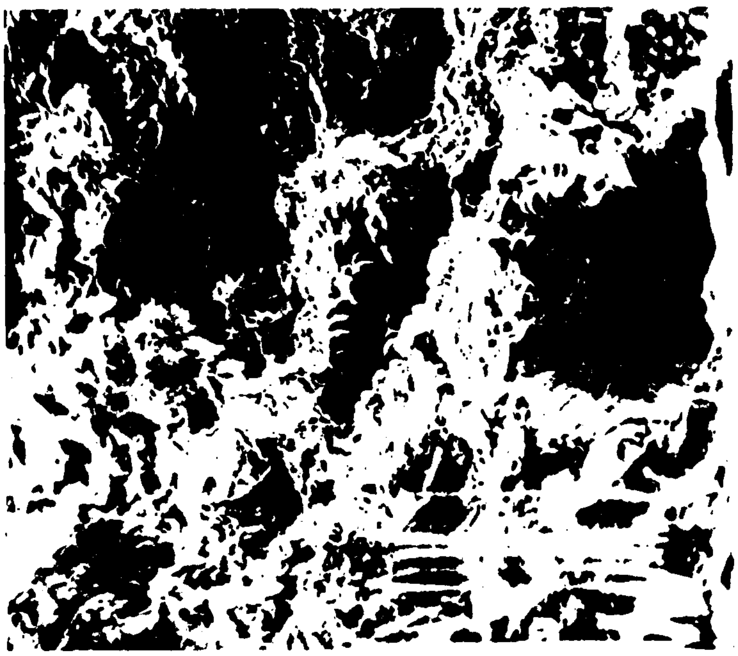
Mechanical tests conducted on new vanes supplied by Ecton showed that the axle required an average load of 346.4 pounds to break the axle from the vane. The standard deviation, for eleven tests, was plus or minus 15.2 pounds. The orientation of the applied load showed no statistical effect on the strength of the piece.

DESCRIPTION OF TESTS

At the request of Ecton Corporation, a fractured surface, located between a compressor vane and its supporting axle, was examined using a scanning electron microscope and energy dispersive x-ray spectrometer (SEM/EDXA) in order to identify the cause of the failure in the piece. The fractured surface was mounted and placed in the instrument. Figure 1 shows a general view of the surface at 50X and 100X. The surface appears contaminated with a film of unknown material, but it is probably the result of handling following the fracture. On the 100X micrograph, two relatively large cavities are visible. One of these cavities appears to exhibit a dendritic structure typical of a free surface during solidification. The round, nodular structured dendrites suggest that these cavities are most likely shrinkage cavities formed during the solidification of the casting which



50X SEM



100X SEM

NOTE: Pores or cavities with dendritic morphology.

Figure 1. Surface of Vane-Axle Failure.

was used to fabricate the vane. Figure 2 shows two different shrinkage cavities on the fractured surface.

The presence of the shrinkage cavities, especially in the numbers present on the surface, suggest that the shear stress present at the vane-axle region were far greater than would exist if a sound casting were used to fabricate the vane. In addition to the increase in stresses resulting from an effective reduction in cross-sectional area, the small cavities also act to concentrate stresses in the vicinity of the cavities. We conclude that the cause of failure was the defective casting.

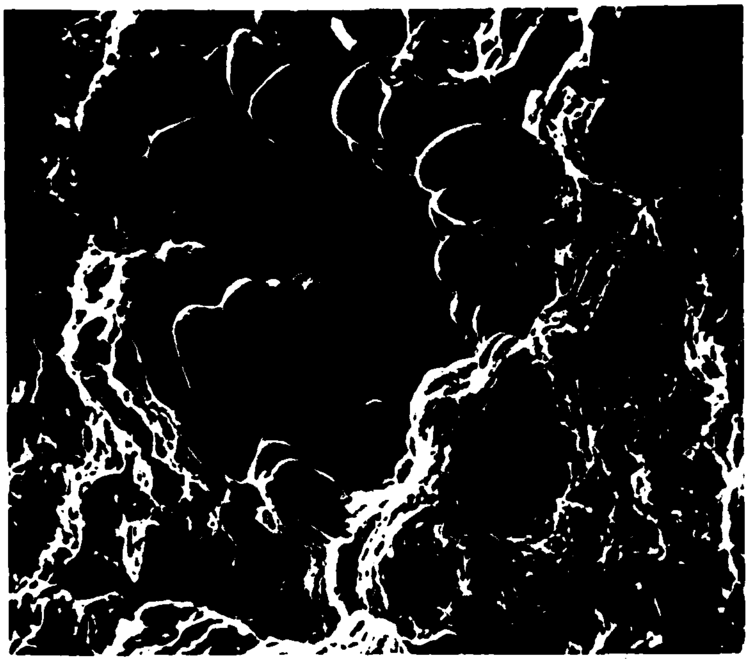
In order to confirm design parameters used by Ecton in the specification of the vane dimensions and affirm the vane-axle configuration was strong enough to meet the requirements of its application, 11 vane-axle interfaces were broken under two shear loading configurations. A test fixture was constructed to allow a mechanical load to be applied to the axle roller co-planar with the vane or perpendicular to the vane. Table 1 shows the loads required to fail the axles.

TABLE 1

SUMMARY OF MECHANICAL TEST DATA

Vane No.	Parallel of Vane Load	Perpendicular to Vane Load
1	365 pounds	350 pounds
2		355 pounds
3	334 pounds	328 pounds
4	400 pounds	370 pounds
5	392 pounds	382 pounds
6	392 pounds	393 pounds

The average fracture load was 346.4 pounds and the standard deviation was plus or minus 15.21 pounds. Appendix 1 contains the actual load-deformation curves for these tests.



300X SEM

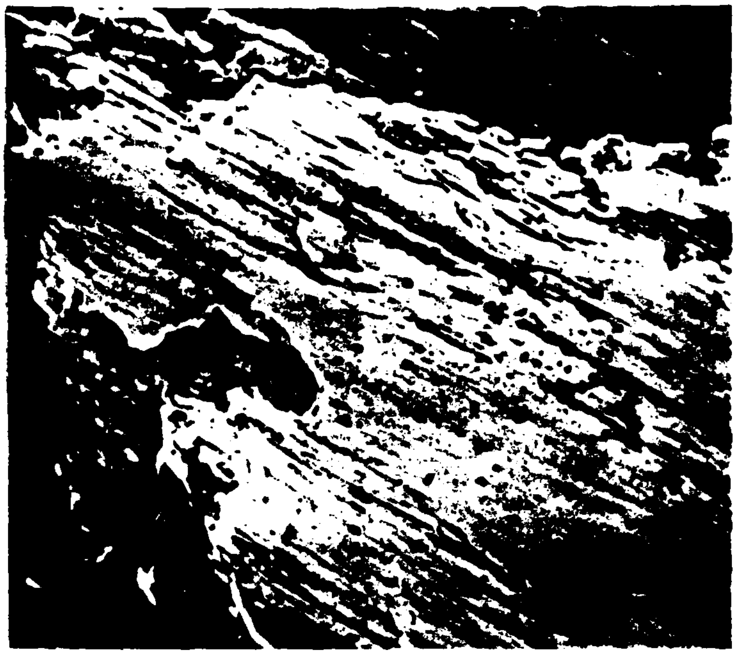
300X SEM

Figure 2. Shrinkage Cavities on Fracture Surface.

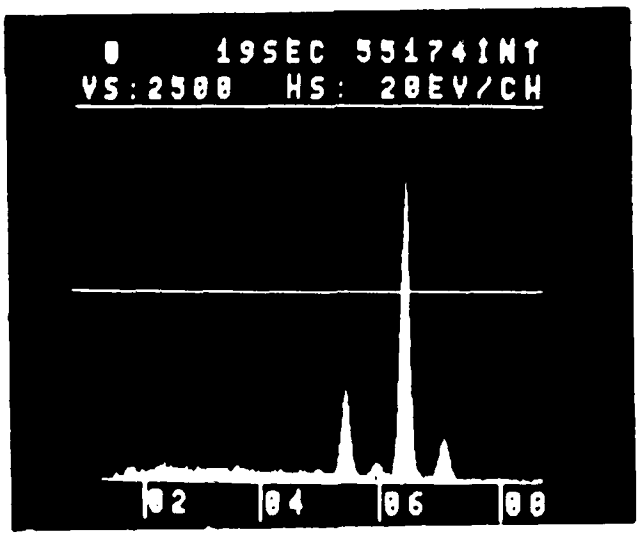
One additional analysis was performed. The surface of the stainless steel ring which supports the vane axles was examined to determine if aluminum particles, resulting from the bench test failure, were burnished onto the surfaces of the retaining ring. The SEM/EDXA was used in this analysis. Figure 3 shows the worn surface of the retaining ring and the x-ray spectrum obtained from that surface. Aluminum was not present in quantities above trace levels. If aluminum particles were smeared onto the surface, one would expect a far higher aluminum concentration.

CONCLUSIONS

The failure of the vane axle in the bench test unit at Ecton was the result of a defective vane which had been fabricated from a defective aluminum casting. The change from cast aluminum to wrought aluminum will prevent this problem in the future, and, based on conversation with Ecton, the fracture strength of the tested vanes indicated they were well within design parameters as far as strength is concerned.



1000X SEM

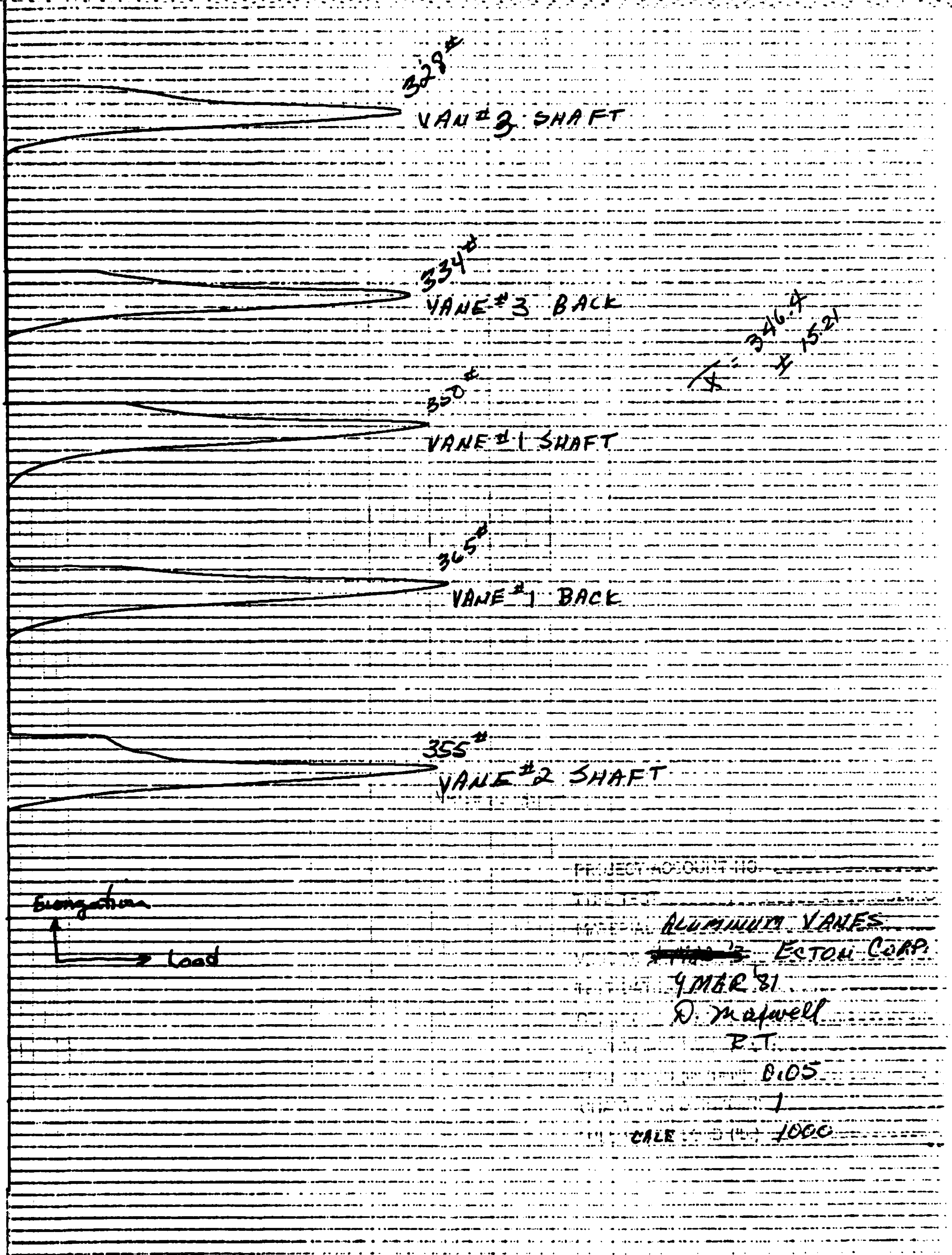


EDXA: Peaks - CrK_{α}, CrK_{β}, FeK_{α}, FeK_{β}

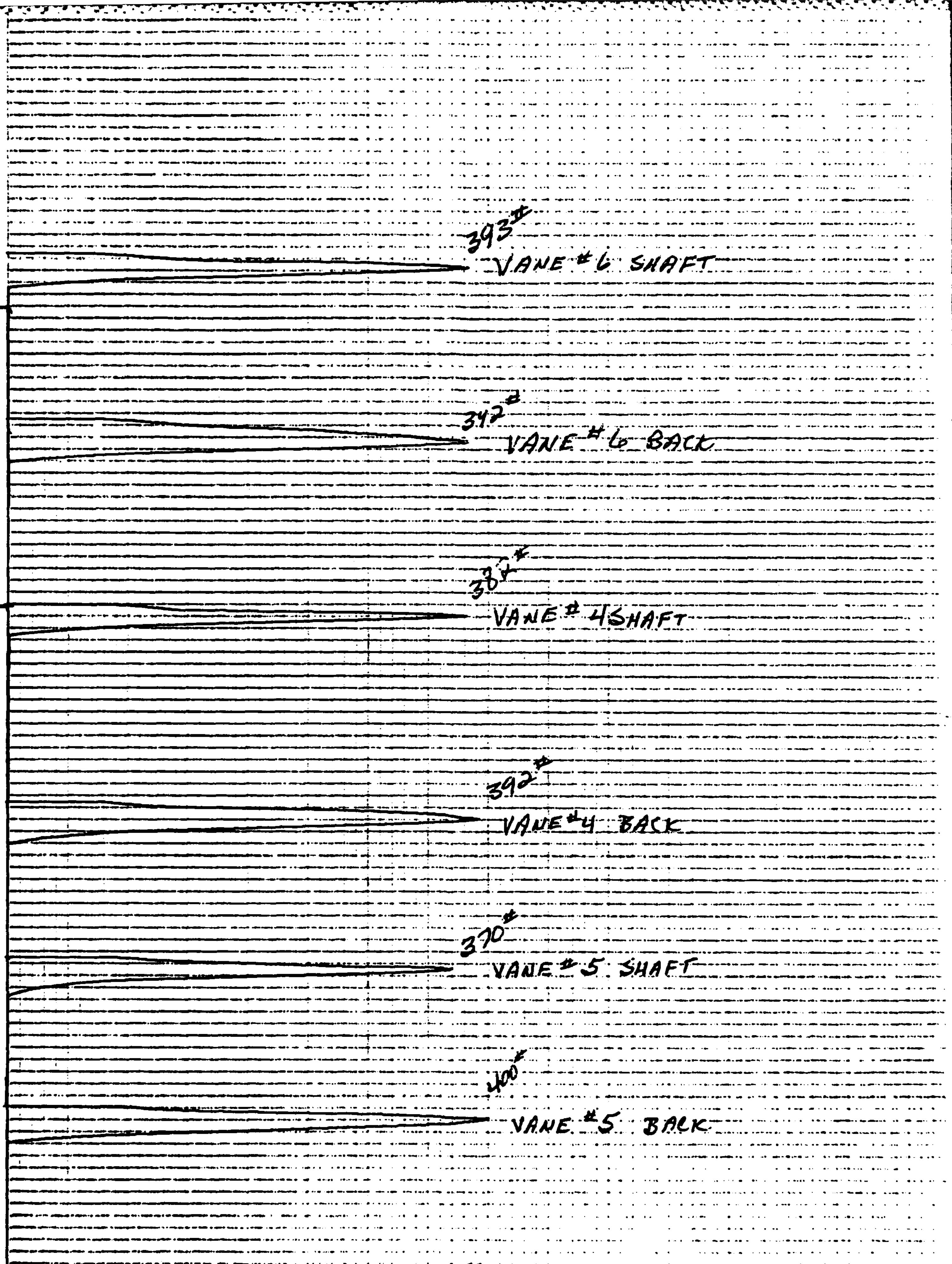
Figure 3. Wear Surface on Retaining Ring.

APPENDIX 1

MECHANICAL TEST DATA



328#
VAN #3 SHAFT
334#
VANE #3 BACK
346.4
15.21
350#
VANE #1 SHAFT
365#
VANE #1 BACK
355#
VANE #2 SHAFT
Elongation
Load
ALUMINUM VANES
ECTON CORP.
4 MAR 81
D. Maxwell
R.T.
0.05
1
CALE
1000



393#
VANE #6 SHAFT
347#
VANE #6 BACK
384#
VANE # 4SHAFT
392#
VANE #4 BACK
370#
VANE #5 SHAFT
400#
VANE #5 BACK

Appendix B

CMP Variable Name List

CMP VARIABLE NAME LIST

Input Variables

VN - Number of vanes in rotor

RVB - Radius of vane bearing, in.

RCB - Radius of cam bearing, in.

EC - Eccentricity, in.

ASR - Ratio, distance vane axle centerline lies below tip of vane/vane height

VH - Vane height, in.

RI - Radius of rotor, in.

ACGR - Ratio, distance that CG of axle piece lies below tip of vane/vane height

HRO - Density of housing material, lb /in

HTH - Wall thickness of cylinder housing, in.

RIMRO - Density of vane bearing rim material, lb /in

RIMT - Combined thickness of vane bearing rim and outer race of vane bearing, in.

RIMW - Width of vane bearing rim, in.

RRO - Density of rotor material, lb /in

SH - Seal height, in.

SRO - Density of vane tip seal material, lb /in

STR - Ratio, thickness of vane tip seal/vane thickness

VRO - Density of vane material, lb /in

WAX - Mass of one vane bearing axle piece, lb

WBRG - Mass of one vane bearing, lb

PHUB - Hub pressure (initial guess), psia

RLG - Rotor length

RPM	- Rotational speed, RPM
R	- Gas constant, lb -ft/lb - R
CP	- Specific heat at constant pressure, BTU/lb - R
FL	- Flow coefficient for outlet port
MU1	- Vane tip sliding friction coefficient
MU2	- Vane slot sliding friction coefficient
PCI	- Compressor inlet manifold presure, psia
TCI	- Compressor inlet manifold temperature, deg R
ACD	- Angle at which vane passes discharge port, RAD.
GAM	- Ratio of specific heats, C /C
OGPM	- Oil flow, gpm
OCP	- Specific heat of oil Btu/lb - R
SPGR	- Specific gravity of oil
BF1	- Vane bearing friction factor
CD	- Dynamic load capacity of vane bearing for 10 cycles, lb
DM	- Pitch diameter of vane bearing rolling elements, in.
E	- Exponent used for calculation of vane bearing life expectancy
FO	- Vane Bearing lubrication factor
LEX	- Exponent in bearing life equation; BL = (dynamic capacity/bearing load)
VISC	- Kinematic viscosity of vane bearing lubricant, centistokes
A123	- Vane bearing life adjustment factor
SCON	- Spring Constant

SLND - Spring length between centerlines, no deflection, in.

VTSC - Vane thickness in sealing contact, in.

RH - Radius of recess, in endplate, to house cams, in.

MURHF - Viscosity of fluid between rotor and endplate, lb -sec/ft

VTSH - Distance vane tip to spring hole centerline, in.

VT - Vane thickness, in.

BFR - Rotor bearing friction factor

CDR - Dynamic load capacity of rotor bearing for 10 cycles, lb

DMR - Pitch diameter of rotor bearing rolling elements, in.

ER - Exponent used for calculation of rotor bearing life expectancy

FOR - Rotor bearing lubrication factor

LEXR - Exponent in bearing life equation: BL = (dynamic capacity/bearing load)

VISCR - Kinematic viscosity of rotor roller bearing lubricant, centictokes

AR123 - Rotor bearing life adjustment factor

BFC - Cam bearing friction factor

CDC - Dynamic load capacity of cam bearing for 10 cycles, lb

DMC - Pitch diameter of cam bearing rolling elements, in.

EEC - Exponent used for calculation of cam bearing life expectancy

FOC - Cam bearing lubrication factor

LEXC - Exponent in bearing life equation: BL = (dynamic capacity/bearing load)

VISCC - Kinematic viscosity of cam bearing lubricant, centistokes

AC123 - Cam bearing life adjustment factor

EPS1 - Rotor/End plate clearance, in.

EPS2 - Vane edge/endplate clearance, in.

EPS3 - Rotor/Stator axial clearance, in.

EPS4 - Vane tip/stator clearance, in.

EPS5 - Vane/Slot clearance, in.

PEPS - Ratio, clearance area not blocked by oil/physical clearance area (oil resistance for above leakage paths)

Performance Outputs

VC1 - Vane cavity volume at compressor inlet, in

VC2 - Vane cavity volume at compressor discharge, in

CVR - Compressor volume ratio, VC2/VC1

TC1 - Gas temperature in compressor cylinder at start of compression process, deg R

TC2 - Gas temperature in compressor cylinder at end of compression process, deg R

CTR - Compressor temperature ratio, TC2/TC1

CDT - Compressor temperature change, TC2-TC1

THUB - Temperature of the gas which has leaked into the cam areas (hub) of the compressor

PC1 - Gas pressure in compressor cylinder at start of compression process, psia

PC2 - Gas pressure in compressor cylinder at end of compression process, psia

PCD - Compressor discharge manifold pressure, psia

CPR - Compressor pressure ratio, PCD/PC1

POP - Compressor discharge port pressure ratio (PCD/PC2)

CDP - Compressor pressure change, PCD-PC1

PHUB - Pressure in compressor hub (acting on base of vanes), psia

CFMI - Ideal flow through the compressor, cfm

FLOCID - Ideal flow through the compressor, lb/min

SCFM - Delivered flow corrected to standard conditions, cfm

FLOCA - Delivered flow, lb/min

WAS	-	Leakage flow across axial seal, lb/min
WHI	-	Leakage flow from hub to inlet, lb/min
WHD	-	Leakage flow from discharge region to hub, lb/min
WV2	-	Leakage flow around vane through area 2 (summation), lb/min
WV4	-	Leakage flow around vane through area 4 (summation), lb/min
WH	-	Leakage flow into or out of the hub, lb/min
WCO	-	Carryover flow (around vane tips), lb/min
ROLHP	-	Horsepower loss in rolling element vane bearings
RBRHPC	-	Horsepower loss in rolling element rotor bearings
VWHP	-	Horsepower loss due to vane sliding in slot
VTHP	-	Horsepower loss due to vane sliding
RHHP	-	Horsepower loss due to rotor/endplate clearance (windage)
VEHHP	-	Horsepower loss due to vane/endplate clearance (windage)
CAMHP	-	Horsepower loss due to cam ring sliding
TORQAV	-	Input torque required, in-lb
SHP	-	Shaft horsepower required due to torque and RPM
HPCI	-	Ideal horsepower required for gas compression process
HPCA	-	Actual horsepower required for gas compression process
HPC	-	Total horsepower required for compression
SUMHP	-	Sum of all sliding and rubbing losses
VOLEFF	-	Volumetric efficiency

MECEFF - Mechanical efficiency

ADEFF - Adiabatic efficiency

COMEFF - Compressor total efficiency

WV - Mass of one vane, lb

WS - Mass of one vane tip seal, lb

RWT - Rotor mass (less vanes and cam rollers), lb

WHSG - Housing mass, lb

WRIM - Mass of one pair of cam roller rims, lb

SUMWT - Sum of all component masses of rotary vaned machine, lb

RVAV - Average vane bearing rotational speed, rpm

FCAV - Average load applied to each vane bearing, lb

BL10 - Life expectancy of one vane bearing (cam roller) at 90% survival rate, hrs rpm

RVL10 - Fatigue life of the vane bearing set in millions of cycles.

RVHR10 - Life expectancy of the complete set of cam bearings for a 90% probability of survival, hours.

FRCAV - Average load applied to each rotor bearing, lb

BRL10 - Life expectancy of one rotor bearing at 90% survival rate, Hrs rpm

RRL10 - Fatigue life of the rotor bearing set in millions of cycles

RRHR10 - Life expectancy of the rotor bearing set at 90% probability of survival, hours

FCCAV - Average load applied to each cam bearing, lb

BCL10 - Life expectancy of one cam bearing at 90% survival rate, Hrs rpm

RCL10 - Fatigue life of the cam bearing set in millions of cycles

RCHR10 - Life expectancy of the cam bearing set at 90% probability of survival, hours rpm

VMRFMX - Maximum (radially outward) deflection at center of vane over 360 of rotation

VMRFMN - Minimum (radially inward) deflection at center of vane over 360 of rotation

VMRSMX - Maximum (radially outward) deflection at center of vane over 360 of rotation

VMRSMN - Minimum (radially inward) deflection at center of vane over 360 rotation

VMTBM - Maximum tangential deflection of vane over 360 of rotation

JVMTBM - Station at which VMTBM occurs

VWPVCM - Maximum vane wall PV value occuring in compressor psi-ft/min

VWPVAV - Average vane wall PV value, psi-ft. min

VVMAX - Maximum sliding velocity in vane slot, ft/min

VTPVCM - Maximum vane tip or tip seal PV value occurring in compressor, psi-ft/min

VTPVAV - Average vane tip or tip seal PV value, psi-ft/min

SVMAX - Maximum sliding velocity at vane tip or tip seal, ft/min

Appendix C

Automatic Data Acquistion Variable Name List

Autommatic Data Acquisition Printout
Variable Name List

PO	Venturi inlet static pressure, Psia
PEI	Compressor inlet static pressure, Psia
PEO	Compressor outlet static pressure, Psia
DELP	Venturi differential pressure, Psid
TORQ	Compressor input shaft torque, ft-lbf
EXC10V	Sensor excitation voltage, VDC
RPM	Compressor input shaft speed, rpm
TROT1	Rotor segment metal temperature, F
TROT2	Rotor segment metal temperature, F
TO	Venturi inlet temperature, F
TEI	Compressor inlet temperature, F
TEO	Compressor outlet temperature, F
THUB	Endplate exterior metal temperature, F
PR	Compressor pressure ratio, PEO/PEI
A-E	Adiabatic Efficency (reference Appendix E)
V-E	Volumetric Efficency (reference Appendix E)
T-E	Isentropic (total) Efficency (reference Appendix E)

Appendix D

ADAS Test Data and Results Printouts

Y159: 16: 37: 40   *8 June 1982*

OPO= 32. 772 01PEI= 26. 783 02PEO= 34. 715 03DELP= . 732 04TORQ= 10. 723
06EXC10V= 9. 995 RPM= 1740. 14TROT1=134. 300 15TROT2=121. 200
OTO= 69. 500 11TEI= 70. 400 12TEO=144. 400 13THUB= 85. 000
PR=1. 296 RPM=1740. A-E=. 552 V-E=. 788 T-E=. 481

Y159: 16: 38: 00

OPO= 32. 839 01PEI= 26. 847 02PEO= 34. 774 03DELP= . 729 04TORQ= 10. 732
06EXC10V= 9. 996 RPM= 1739. 14TROT1=134. 000 15TROT2=122. 800
OTO= 69. 500 11TEI= 70. 400 12TEO=144. 400 13THUB= 85. 000
PR=1. 295 RPM=1739. A-E=. 550 V-E=. 786 T-E=. 480

Y159: 16: 42: 52

OPO= 34. 952 01PEI= 26. 860 02PEO= 36. 725 03DELP= . 648 04TORQ= 11. 913
06EXC10V= 9. 996 RPM= 1730. 14TROT1=131. 700 15TROT2=126. 100
OTO= 69. 800 11TEI= 70. 700 12TEO=155. 600 13THUB= 85. 000
PR=1. 367 RPM=1730. A-E=. 585 V-E=. 771 T-E=. 516

Y159: 16: 43: 12

OPO= 34. 992 01PEI= 26. 908 02PEO= 36. 782 03DELP= . 647 04TORQ= 11. 895
06EXC10V= 9. 996 RPM= 1732. 14TROT1=128. 500 15TROT2=129. 500
OTO= 69. 700 11TEI= 70. 700 12TEO=155. 800 13THUB= 85. 000
PR=1. 367 RPM=1732. A-E=. 583 V-E=. 769 T-E=. 516

Y159: 16: 47: 52

OPO= 37. 983 01PEI= 26. 813 02PEO= 39. 632 03DELP= . 566 04TORQ= 13. 720
06EXC10V= 9. 995 RPM= 1722. 14TROT1=148. 400 15TROT2=167. 800
OTO= 70. 200 11TEI= 71. 000 12TEO=171. 600 13THUB= 84. 800
PR=1. 478 RPM=1722. A-E=. 624 V-E=. 758 T-E=. 556

Y159: 16: 48: 12

OPO= 38. 077 01PEI= 26. 877 02PEO= 39. 726 03DELP= . 565 04TORQ= 13. 741
06EXC10V= 9. 994 RPM= 1721. 14TROT1=144. 600 15TROT2=162. 400
OTO= 70. 200 11TEI= 71. 100 12TEO=171. 700 13THUB= 84. 800
PR=1. 478 RPM=1721. A-E=. 624 V-E=. 758 T-E=. 556

Y139: 16: 54: 16

OPO= 43. 423 01PEI= 27. 856 02PEO= 44. 784 03DELP= . 449 04TORQ= 16. 415
06EXC10V= 9. 994 RPM= 1724. 14TROT1=153. 600 15TROT2=173. 800
OTO= 70. 600 11TEI= 71. 400 12TEO=196. 200 13THUB= 84. 500
PR=1. 606 RPM=1724. A-E=. 619 V-E=. 697 T-E=. 546

Y159: 16: 54: 36

OPO= 43. 492 01PEI= 28. 019 02PEO= 44. 936 03DELP= . 450 04TORQ= 16. 411
06EXC10V= 9. 993 RPM= 1724. 14TROT1=157. 300 15TROT2=201. 000
OTO= 70. 600 11TEI= 71. 400 12TEO=196. 400 13THUB= 84. 500
PR=1. 604 RPM=1724. A-E=. 615 V-E=. 695 T-E=. 545

Y159: 16: 59: 15

OPO= 46. 249 01PEI= 28. 512 02PEO= 47. 487 03DELP= . 401 04TORQ= 17. 876
06EXC10V= 9. 989 RPM= 1717. 14TROT1=167. 100 15TROT2=167. 300

Y159: 16: 59: 35

OPO= 46. 249 01PEI= 28. 483 02PEO= 47. 480 03DELP= .400 04TORQ= 17. 859
06EXC10V= 9. 989 RPM= 1716. 14TROT1=167. 300 15TROT2=175. 500
OTO= 70. 700 11TEI= 71. 400 12TEO=211. 900 13THUB= 84. 500
PR=1. 667 RPM=1716. A-E=. 595 V-E=. 669 T-E=. 533

8 June 1982 (Cont.)

Y159: 17: 01: 46

OPO= 45. 150 01PEI= 27. 729 02PEO= 46. 354 03DELP= .392 04TORQ= 17. 500
06EXC10V= 9. 990 RPM= 1722. 14TROT1=169. 600 15TROT2=207. 900
OTO= 71. 000 11TEI= 71. 600 12TEO=214. 100 13THUB= 84. 500
PR=1. 672 RPM=1722. A-E=. 590 V-E=. 669 T-E=. 533

Y159: 17: 02: 06

OPO= 44. 915 01PEI= 27. 582 02PEO= 46. 131 03DELP= .390 04TORQ= 17. 422
06EXC10V= 9. 990 RPM= 1722. 14TROT1=169. 800 15TROT2=197. 800
OTO= 71. 000 11TEI= 71. 700 12TEO=214. 300 13THUB= 84. 500
PR=1. 672 RPM=1722. A-E=. 591 V-E=. 669 T-E=. 533

Y159: 17: 06: 01

OPO= 48. 878 01PEI= 27. 927 02PEO= 49. 892 03DELP= .322 04TORQ= 19. 715
06EXC10V= 9. 988 RPM= 1712. 14TROT1=183. 300 15TROT2=284. 700
OTO= 71. 500 11TEI= 72. 000 12TEO=236. 200 13THUB= 84. 600
PR=1. 787 RPM=1712. A-E=. 585 V-E=. 632 T-E=. 513

Y159: 17: 06: 21

OPO= 48. 953 01PEI= 28. 025 02PEO= 49. 977 03DELP= .325 04TORQ= 19. 729
06EXC10V= 9. 988 RPM= 1713. 14TROT1=184. 100 15TROT2=318. 600
OTO= 71. 500 11TEI= 72. 100 12TEO=236. 600 13THUB= 84. 700
PR=1. 783 RPM=1713. A-E=. 582 V-E=. 632 T-E=. 513

Y159: 17: 13: 52

OPO= 53. 328 01PEI= 28. 002 02PEO= 54. 298 03DELP= .274 04TORQ= 22. 459
06EXC10V= 9. 988 RPM= 1728. 14TROT1=211. 100 15TROT2=311. 600
OTO= 72. 200 11TEI= 72. 800 12TEO=269. 900 13THUB= 84. 700
PR=1. 939 RPM=1728. A-E=. 563 V-E=. 603 T-E=. 498

Y159: 17: 14: 12

OPO= 53. 428 01PEI= 28. 101 02PEO= 54. 348 03DELP= .275 04TORQ= 22. 536
06EXC10V= 9. 988 RPM= 1727. 14TROT1=213. 800 15TROT2=297. 100
OTO= 72. 300 11TEI= 72. 800 12TEO=270. 600 13THUB= 84. 700
PR=1. 934 RPM=1727. A-E=. 559 V-E=. 602 T-E=. 495

Y159: 17: 20: 01

OPO= 54. 762 01PEI= 27. 848 02PEO= 55. 734 03DELP= .253 04TORQ= 23. 490
06EXC10V= 9. 988 RPM= 1715. 14TROT1=227. 000 15TROT2=363. 600

```
Y159:17:20:21

OPO= 54.842 01PEI= 27.910 02PEO= 55.827 03DELP=    .254 04TORQ= 23.489
06EXCIOV=  9.988 RPM= 1714.  14TROT1=227.900 15TROT2=402.800
OTO= 72.900 11TEI= 73.400 12TEO=286.800 13THUB= 84.900
PR=2.000 RPM=1714.  A-E=.548 V-E=.595 T-E=.493

Y159:17:27:23

OPO= 57.527 01PEI= 27.822 02PEO= 58.338 03DELP=    .221 04TORQ= 25.153
C6EXC10V=  9.988 RPM= 1714.  14TROT1=249.000 15TROT2=389.600
OTO= 73.400 11TEI= 73.800 12TEO=311.200 13THUB= 84.800
PR=2.097 RPM=1714.  A-E=.530 V-E=.571 T-E=.473

Y159:17:27:42

OPO= 57.537 01PEI= 27.863 02PEO= 58.405 03DELP=    .220 04TORQ= 25.235
06EXCIOV=  9.988 RPM= 1713.  14TROT1=249.500 15TROT2=427.400
OTO= 73.400 11TEI= 73.800 12TEO=311.600 13THUB= 84.800
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8 June 1982 (Cont.)

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Y159:17:43:33

OPO= 38.740 01PEI= 26.164 02PEO= 39.327 03DELP=  1.087 04TORQ= 12.952
06EXC10V=  9.988 RPM= 1073.  14TROT1=191.600 15TROT2=311.100
OTO= 71.300 11TEI= 73.300 12TEO=219.100 13THUB= 84.700
PR=1.503 RPM=1073.  A-E=.452 V-E=17*3 T-E=13*7

Y159:17:44:05

OPO= 38.766 01PEI= 26.148 02PEO= 39.351 03DELP=  1.084 04TORQ= 12.959
06EXC10V=  9.989 RPM= 1073.  14TROT1=190.400 15TROT2=311.700
OTO= 71.100 11TEI= 73.100 12TEO=218.500 13THUB= 84.600
PR=1.505 RPM=1073.  A-E=.454 V-E=17*3 T-E=13*7s

Y159:18:12:05

OPO= 33.627 01PEI= 26.290 02PEO= 36.313 03DELP=   .975 04TORQ= 12.150
06EXC10V=  9.986 RPM= 2008.  14TROT1=218.300 15TROT2=126.100
OTO= 69.000 11TEI= 69.600 12TEO=159.800 13THUB= 81.700
PR=1.381 RPM=2008.  A-E=.568 V-E=.809 T-E=.538

Y159:18:12:25

OPO= 33.637 01PEI= 26.315 02PEO= 36.301 03DELP=   .986 04TORQ= 12.180
06EXC10V=  9.986 RPM= 2007.  14TROT1=227.100 15TROT2=134.700
OTO= 69.000 11TEI= 69.500 12TEO=159.800 13THUB= 81.700
PR=1.379 RPM=2007.  A-E=.565 V-E=.813 T-E=.538

Y159:18:17:27

OPO= 37.157 01PEI= 26.067 02PEO= 39.333 03DELP=   .795 04TORQ= 13.999
06EXC10V=  9.986 RPM= 2005.  14TROT1=168.200 15TROT2=164.700
OTO= 69.500 11TEI= 70.000 12TEO=177.200 13THUB= 81.700
PR=1.509 RPM=2005.  A-E=.617 V-E=.781 T-E=.577

Y159:18:17:47

OPO= 37.276 01PEI= 26.156 02PEO= 39.439 03DELP=   .797 04TORQ= 14.079
06EXC10V=  9.985 RPM= 2003.  14TROT1=165.800 15TROT2=162.200
OTO= 69.600 11TEI= 70.000 12TEO=177.300 13THUB= 81.700
PR=1.508 RPM=2003.  A-E=.615 V-E=.781 T-E=.574

Y159:18:20:41

OPO= 39.591 01PEI= 26.268 02PEO= 41.487 03DELP=   .706 04TORQ= 15.240
06EXC10V=  9.985 RPM= 1991.  14TROT1=149.700 15TROT2=203.600
OTO= 69.800 11TEI= 70.200 12TEO=188.000 13THUB= 81.700
PR=1.579 RPM=1991.  A-E=.628 V-E=.762 T-E=.582

Y159:18:21:01

OPO= 39.736 01PEI= 26.427 02PEO= 41.660 03DELP=   .710 04TORQ= 15.275
06EXC10V=  9.985 RPM= 1991.  14TROT1=154.200 15TROT2=103.800
OTO= 69.900 11TEI= 70.200 12TEO=188.300 13THUB= 81.700
PR=1.576 RPM=1991.  A-E=.624 V-E=.760 T-E=.581

Y159:18:26:32

OPO= 46.202 01PEI= 27.927 02PEO= 47.842 03DELP=   .565 04TORQ= 18.452
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Y159:18:26:52

OPO= 46.262 01PEI= 27.891 02PEO= 47.929 03DELP=    .587 04TORQ= 18.436
06EXC10V=  9.984 RPM= 1973.  14TROT1=171.300 15TROT2=348.600
OTO= 70.700 11TEI= 70.900 12TEO=213.200 13THUB= 81.700
PR=1.718 RPM=1973.  A-E=.625 V-E=.717 T-E=.577

Y159:18:33:36

OPO= 48.783 01PEI= 28.097 02PEO= 50.373 03DELP=    .542 04TORQ= 19.854
06EXC10V=  9.984 RPM= 1994.  14TROT1=182.500 15TROT2=498.400
OTO= 71.800 11TEI= 71.900 12TEO=229.800 13THUB= 81.900
PR=1.793 RPM=1994.  A-E=.612 V-E=.697 T-E=.569

Y159:18:33:56

OPC= 48.806 01PEI= 28.156 02PEO= 50.418 03DELP=    .547 04TORQ= 19.817
06EXC10V=  9.984 RPM= 1993.  14TROT1=195.400 15TROT2=568.400
OTO= 71.800 11TEI= 71.800 12TEO=229.900 13THUB= 81.800
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PR=1.791 RPM=1993.  A-E=.610 V-E=.699 T-E=.572

Y159:18:53:49

OPO= 52.546 01PEI= 28.011 02PEO= 54.092 03DELP=    .443 04TORQ= 22.155
06EXC10V=  9.983 RPM= 1995.  14TROT1=218.300 15TROT2=444.000
OTO= 72.600 11TEI= 72.500 12TEO=258.400 13THUB= 81.600
PR=1.931 RPM=1995  A-E=.593 V-E=.657 T-E=.546

Y159:18:54:09

OPO= 52.594 01PEI= 28.015 02PEO= 54.109 03DELP=    .446 04TORQ= 22.147
06EXC10V=  9.983 RPM= 1995.  14TROT1=254.600 15TROT2=550.000
OTO= 72.600 11TEI= 72.600 12TEO=258.600 13THUB= 81.600
PR=1.931 RPM=1995  A-E=.593 V-E=.659 T-E=.549

Y159:19:00:28

OPO= 53.639 01PEI= 26.227 02PEO= 55.046 03DELP=    .363 04TORQ= 23.272
06EXC10V=  9.984 RPM= 1992.  14TROT1=228.600 15TROT2=442.000
OTO= 73.000 11TEI= 73.000 12TEO=283.400 13THUB= 81.300
PR=2.099 RPM=1992.  A-E=.598 V-E=.644 T-E=.544

Y159:19:00:48

OPO= 53.604 01PEI= 26.254 02PEO= 55.054 03DELP=    .364 04TORQ= 23.294
06EXC10V=  9.983 RPM= 1993.  14TROT1=223.900 15TROT2=506.100
OTO= 73.000 11TEI= 73.100 12TEO=283.900 13THUB= 81.300
PR=2.097 RPM=1993.  A-E=.596 V-E=.644 T-E=.543

Y159:19:04:34

OPO= 58.880 01PEI= 27.519 02PEO= 60.279 03DELP=    .332 04TORQ= 25.953
06EXC10V=  9.984 RPM= 1989.  14TROT1=258.200 15TROT2=527.900
OTO= 73.400 11TEI= 73.200 12TEO=308.500 13THUB= 81.200
PR=2.190 RPM=1989.  A-E=.569 V-E=.616 T-E=.521

Y159:19:04:54

OPO= 58.876 01PEI= 27.502 02PEO= 60.255 03DELP=    .333 04TORQ= 25.905
06EXC10V=  9.983 RPM= 1989.  14TROT1=246.000 15TROT2=689.400
OTO= 73.400 11TEI= 73.300 12TEO=308.500 13THUB= 81.300
PR=2.191 RPM=1989.  A-E=.570 V-E=.618 T-E=.524

Y159:19:15:13

OPO= 30.553 01PEI= 22.892 02PEO= 33.095 03DELP=    .951 04TORQ= 11.957
06EXC10V=  9.984 RPM= 2202.  14TROT1=200.600 15TROT2=398.700
OTO= 70.900 11TEI= 71.500 12TEO=183.300 13THUB= 81.100
PR=1.446 RPM=2202.  A-E=.528 V-E=.797 T-E=.538

Y159:19:15:33

OPO= 30.546 01PEI= 22.948 02PEO= 33.124 03DELP=    .958 04TORQ= 12.003
06EXC10V=  9.983 RPM= 2200.  14TROT1=190.100 15TROT2=410.400
OTO= 70.800 11TEI= 71.500 12TEO=183.000 13THUB= 81.100
PR=1.443 RPM=2200.  A-E=.527 V-E=.798 T-E=.536

Y159:19:22:19

OPO= 37.535 01PEI= 26.723 02PEO= 40.069 03DELP=    .993 04TORQ= 14.451
06EXC10V=  9.984 RPM= 2186.  14TROT1=203.800 15TROT2=343.700
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Y159: 19: 22: 38

OPO= 37.629 01PEI= 26.855 02PEO= 40.211 03DELP=   .994 04TORQ= 14.488
06EXC10V=  9.983 RPM= 2186.  14TROT1=212.300 15TROT2=354.500
OTO= 70.600 11TEI= 70.900 12TEO=184.200 13THUB= 80.600
PR=1.497 RPM=2186.  A-E=.573 V-E=.780 T-E=.562

Y159: 19: 26: 29

OPO= 41.570 01PEI= 26.935 02PEO= 43.945 03DELP=   .852 04TORQ= 16.494
06EXC10V=  9.983 RPM= 2199.  14TROT1=201.000 15TROT2=194.600
OTO= 70.900 11TEI= 71.000 12TEO=199.500 13THUB= 80.500
PR=1.632 RPM=2199.  A-E=.621 V-E=.756 T-E=.589

Y159: 19: 26: 49

OPO= 41.705 01PEI= 27.047 02PEO= 43.997 03DELP=   .863 04TORQ= 16.512
06EXC10V=  9.983 RPM= 2201.  14TROT1=180.800 15TROT2=212.100
OTO= 70.900 11TEI= 71.000 12TEO=199.700 13THUB= 80.500
PR=1.627 RPM=2201.  A-E=.616 V-E=.758 T-E=.589

Y159: 19: 30: 46

OPO= 45.446 01PEI= 27.622 02PEO= 47.553 03DELP=   .766 04TORQ= 18.320
06EXC10V=  9.983 RPM= 2189.  14TROT1=177.800 15TROT2=242.100
OTO= 71.500 11TEI= 71.400 12TEO=214.000 13THUB= 80.500
PR=1.722 RPM=2189.  A-E=.626 V-E=.736 T-E=.593

Y159: 19: 31: 06

OPO= 45.251 01PEI= 27.398 02PEO= 47.376 03DELP=   .760 04TORQ= 18.283
06EXC10V=  9.983 RPM= 2190.  14TROT1=187.400 15TROT2=256.700
OTO= 71.500 11TEI= 71.500 12TEO=214.300 13THUB= 80.500
PR=1.729 RPM=2190.  A-E=.631 V-E=.738 T-E=.595E

Y159: 19: 34: 40

OPO= 47.412 01PEI= 27.558 02PEO= 49.401 03DELP=   .694 04TORQ= 19.403
06EXC10V=  9.982 RPM= 2189.  14TROT1=181.800 15TROT2=326.900
OTO= 71.900 11TEI= 71.900 12TEO=224.700 13THUB= 80.600
PR=1.793 RPM=2189.  A-E=.632 V-E=.72[illegible] T-E=.590B= 8

Y159: 19: 35: 00

OPO= 47.487 01PEI= 27.589 02PEO= 49.504 03DELP=   .700 04TORQ= 19.456
06EXC10V=  9.982 RPM= 2188.  14TROT1=191.000 15TROT2=225.000
OTO= 72.000 11TEI= 71.800 12TEO=225.000 13THUB= 80.500
PR=1.794 RPM=2188.  A-E=.631 V-E=.722 T-E=.592

Y159: 19: 41: 24

OPO= 53.095 01PEI= 28.528 02PEO= 54.832 03DELP=   .617 04TORQ= 22.353
06EXC10V=  9.981 RPM= 2190.  14TROT1=208.300 15TROT2=177.600
OTO= 73.000 11TEI= 72.700 12TEO=248.700 13THUB= 80.700
PR=1.922 RPM=2190.  A-E=.622 V-E=.695 T-E=.579

Y159: 19: 41: 44

OPO= 53.080 01PEI= 28.520 02PEO= 54.799 03DELP=   .613 04TORQ= 22.322
06EXC10V=  9.981 RPM= 2189.  14TROT1=200.000 15TROT2=165.600
OTO= 73.000 11TEI= 72.600 12TEO=248.900 13THUB= [illegible] 600
PR=1.921 RPM=2189.  A-E=.620 V-E=.693 T-E=.578
```

```
06EXC10V=  9.981 RPM= 2194.  14TROT1=211.400 15TROT2=209.100
OTO= 73.400 11TEI= 73.100 12TEO=266.400 13THUB= 80.200
PR=2.030 RPM=2194  A-E=.619 V-E=.683 T-E=.575

Y159:19:46:47

OPO= 53.245 01PEI= 27.008 02PEO= 54.749 03DELP=   .530 04TORQ= 22.805
06EXC10V=  9.981 RPM= 2192.  14TROT1=211.100 15TROT2=185.300
OTO= 73.400 11TEI= 73.100 12TEO=266.600 13THUB= 80.200
PR=2.027 RPM=2192.  A-E=.617 V-E=.682 T-E=.575

Y159:19:51:29

OPO= 54.430 01PEI= 26.680 02PEO= 55.765 03DELP=   .480 04TORQ= 23.558
06EXC10V=  9.982 RPM= 2178.  14TROT1=223.200 15TROT2=229.100
OTO= 73.700 11TEI= 73.500 12TEO=280.500 13THUB= 80.300
PR=2.090 RPM=2178.  A-E=.605 V-E=.669 T-E=.565

Y159:19:51:49

OPO= 54.445 01PEI= 26.674 02PEO= 55.788 03DELP=   .482 04TORQ= 23.569
06EXC10V=  9.982 RPM= 2178.  14TROT1=227.600 15TROT2=249.800
OTO= 73.800 11TEI= 73.500 12TEO=280.900 13THUB= 80.300
```

9 June 1982

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Y160: 18: 00: 04

OPO= 35. 804 01PEI= 27. 357 02PEO= 38. 634 03DELP=   1. 102 04TORQ= 13. 416
06EXC10V=   9. 984 RPM= 2003.  14TROT1=149. 300 15TROT2=182. 900
OTO= 70. 100 11TEI= 71. 000 12TEO=160. 400 13THUB= 81. 800
PR=1. 412 RPM=2003.  A-E=. 616 V-E=. 856 T-E=. 575

Y160: 18: 00: 24

OPO= 35. 878 01PEI= 27. 326 02PEO= 38. 758 03DELP=   1. 109 04TORQ= 13. 401
06EXC10V=   9. 985 RPM= 2002.  14TROT1=160. 800 15TROT2=199. 100
OTO= 70. 100 11TEI= 71. 000 12TEO=160. 400 13THUB= 81. 700
PR=1. 418 RPM=2002.  A-E=. 624 V-E=. 861 T-E=. 586

Y160: 18: 04: 21

OPO= 38. 074 01PEI= 27. 057 02PEO= 40. 514 03DELP=    . 941 04TORQ= 14. 474
06EXC10V=   9 983 RPM= 2001.  14TROT1=140. 300 15TROT2=112. 900
OTO= 70. 200 11TEI= 71. 200 12TEO=171. 000 13THUB= 81. 900
PR=1. 497 RPM=2001  A-E=. 65  V-E=. 830 T-E=. 603

Y160: 18: 04. 41

OPO= 38. 209 01PEI= 27. 156 02PEO= 40. 612 03DELP=    . 943 04TORQ= 14. 541
06EXC10V=   9. 983 RPM= 1996.  14TROT1=144. 700 15TROT2=144. 500
OTO= 70. 200 11TEI= 71. 200 12TEO=171. 200 13THUB= 81. 900
PR=1. 495 RPM=1996.  A-E=. 648 V-E=. 831 T-E= 601

Y160: 18: 08: 23

OPO= 43. 061 01PEI= 27. 991 02PEO= 45. 190 03DELP=    . 819 04TORQ= 16. 773
06EXC10V=   9. 984 RPM= 1988.  14TROT1=148 200 15TROT2=214. 300
OTO= 70. 700 11TEI= 71. 400 12TEO=186. 500 13THUB= 81. 800
PR=1. 614 RPM=1988.  A-E= 677 V-E=. 805 T-E= 626

Y160: 18: 08: 43

OPO= 43. 156 01PEI= 28. 130 02PEO= 45 330 03DELP=    . 822 04TORQ= 16. 901
06EXC10V=   9. 984 RPM= 1990.  14TROT1=178 100 15TROT2=209  00
OTO= 70 800 11TEI= 71. 500 12TEO=186 900 13THUB= 81. 900
PR=1. 6   RPM=1990.  A-E=. 673 V-E= 802 T-E= 620

Y160: 18: 11: 47

OPO= 44. 372 01PEI= 27. 222 02PEO= 46. 259 03DELP=    . 725 04TORQ= 17. 779
06EXC10V=   9. 985 RPM= 1989  14TROT1=151. 500 15TROT2= 94. 900
OTO= 71. 200 11TEI= 71. 900 12TEO=198. 900 13THUB= 81. 900
PR=1. 699 RPM=1989.  A-E=. 685 V-E= 792 T-E= 630

Y160: 18: 12: 07

OPO= 44. 437 01PEI= 27. 255 02PEO= 46. 570 03DELP=    . 723 04TORQ= 17. 825
06EXC10V=   9. 985 RPM= 1993.  14TROT1=157 300 15TROT2= 90. 000
OTO= 71. 300 11TEI= 71. 900 12TEO=199. 100 13THUB= 81. 900
PR=1. 701 RPM=1993.  A-E=. 686 V-E=. 789 T-E=. 629

Y160: 18: 15: 37

OPO= 47. 477 01PEI= 27 416 02PEO= 49. 284 03DELP=    . 657 04TORQ= 19. 450
06EXC10V=   9. 984 RPM= 2002  14TROT1=166 900 15TROT2=245. 200
OTO= 71. 800 11TEI= 72. 200 12TEO=213. 300 13THUB= 82. 000
PR=1. 798 RPM=2002. A-E=. 688 V-E=. 771 T-E=. 630
```

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OPO= 47.602 01PEI= 27.459 02PEO= 49.419 03DELP=   .662 04TORQ= 19.544
06EXC10V=  9.984 RPM= 2000.  14TROT1=195.300 15TROT2=177.500
OTO= 71.900 11TEI= 72.300 12TEO=213.500 13THUB= 82.000
PR=1.800 RPM=2000.  A-E=.690 V-E=.774 T-E=.632

Y160: 18: 19: 45

OPO= 51.173 01PEI= 27.878 02PEO= 52.855 03DELP=   .590 04TORQ= 21.411
06EXC10V=  9.983 RPM= 1999.  14TROT1=190.200 15TROT2=244.800
OTO= 72.300 11TEI= 72.600 12TEO=229.500 13THUB= 81.800
PR=1.896 RPM=1999.  A-E=.681 V-E=.749 T-E=.621

Y160: 18: 20: 05

OPO= 51.243 01PEI= 27.835 02PEO= 52.975 03DELP=   .593 04TORQ= 21.390
06EXC10V=  9.983 RPM= 2001.  14TROT1=215.600 15TROT2=207.300
OTO= 72.400 11TEI= 72.600 12TEO=230.000 13THUB= 81.800
PR=1.903 RPM=2001.  A-E=.683 V-E=.752 T-E=.626

Y160: 18: 24: 24
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9 June 1982 (Cont.)

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OPO= 54.790 01PEI= 28.319 02PEO= 56.472 03DELP=    .533 04TORQ= 23.289
06EXC10V=  9.982 RPM= 1989.  14TROT1=186.700 15TROT2=379.900
OTO= 73.000 11TEI= 73.200 12TEO=247.100 13THUB= 81.500
PR=1.994 RPM=1989.  A-E=.669 V-E=.730 T-E=.615

Y160:18:28:44

OPO= 55.286 01PEI= 28.690 02PEO= 56.911 03DELP=    .535 04TORQ= 23.452
06EXC10V=  9.981 RPM= 1989.  14TROT1=190.800 15TROT2=257.200
OTO= 73.600 11TEI= 73.800 12TEO=250.200 13THUB= 81.400
PR=1.984 RPM=1989.  A-E=.654 V-E=.726 T-E=.610

Y160:18:28:59

OPO= 55.366 01PEI= 28.637 02PEO= 56.900 03DELP=    .537 04TORQ= 23.467
06EXC10V=  9.982 RPM= 1986.  14TROT1=193.400 15TROT2=307.200
OTO= 73.600 11TEI= 73.800 12TEO=250.400 13THUB= 81.400
PR=1.987 RPM=1986.  A-E=.655 V-E=.730 T-E=.613

Y160:18:35:02

OPO= 58.526 01PEI= 28.498 02PEO= 60.242 03DELP=    .477 04TORQ= 25.265
06EXC10V=  9.983 RPM= 1992.  14TROT1=209.200 15TROT2=263.500
OTO= 74.300 11TEI= 74.400 12TEO=269.800 13THUB= 81.700
PR=2.114 RPM=1992.  A-E=.653 V-E=.710 T-E=.607

Y160:18:35:22

OPO= 58.576 01PEI= 28.494 02PEO= 60.272 03DELP=    .479 04TORQ= 25.328
06EXC10V=  9.983 RPM= 1991.  14TROT1=208.300 15TROT2=409.500
OTO= 74.200 11TEI= 74.400 12TEO=269.900 13THUB= 81.700
PR=2.115 RPM=1991.  A-E=.653 V-E=.712 T-E=.608

Y160:18:37:58

OPO= 59.501 01PEI= 27.581 02PEO= 61.026 03DELP=    .420 04TORQ= 26.017
06EXC10V=  9.983 RPM= 1985.  14TROT1=219.700 15TROT2=487.300
OTO= 74.200 11TEI= 74.500 12TEO=283.300 13THUB= 81.800
PR=2.213 RPM=1985  A-E=.652 V-E=.697 T-E=.596

Y160:18:38:18

OPO= 59.552 01PEI= 27.569 02PEO= 61.100 03DELP=    .421 04TORQ= 26.084
06EXC10V=  9.982 RPM= 1989.  14TROT1=219.100 15TROT2=537.400
OTO= 74.200 11TEI= 74.500 12TEO=283.800 13THUB= 81.800

PR=2.216 RPM=1989.  A-E=.652 V-E=.697 T-E=.598

Y160:18:42:32

OPO= 61.125 01PEI= 27.252 02PEO= 62.566 03DELP=    .396 04TORQ= 27.006
06EXC10V=  9.985 RPM= 2006.  14TROT1=230.300 15TROT2=366.100
OTO= 74.600 11TEI= 74.800 12TEO=297.300 13THUB= 81.800
PR=2.296 RPM=2006  A-E=.645 V-E=.688 T-E=.591

Y160:18:42:52

OPO= 61.256 01PEI= 27.295 02PEO= 62.693 03DELP=    .396 04TORQ= 27.06?
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Y160: 18: 51: 19

OPO= 31. 620 01PEI= 25. 102 02PEO= 35. 110 03DELP=  1. 273 04TORQ= 12. 322
06EXC10V=  9. 985 RPM= 2201.  14TROT1=187. 100 15TROT2=186. 800
OTO= 72. 100 11TEI= 73. 000 12TEO=174. 000 13THUB= 81. 800
PR=1. 399 RPM=2201.  A-E=. 531 V-E=. 852 T-E=. 555

Y160: 18: 51: 39

OPO= 31. 643 01PEI= 25. 012 02PEO= 35. 066 03DELP=  1. 255 04TORQ= 12. 419
06EXC10V=  9. 984 RPM= 2204.  14TROT1=187. 500 15TROT2=207. 600
OTO= 72. 000 11TEI= 72. 900 12TEO=173. 600 13THUB= 81. 800

PR=1. 402 RPM=2204.  A-E=. 537 V-E=. 848 T-E=. 550

Y160: 19: 01: 18

OPO= 34. 237 01PEI= 24. 770 02PEO= 37. 032 03DELP=  1. 115 04TORQ= 13. 582
06EXC10V=  9. 986 RPM= 2194.  14TROT1=156 900 15TROT2=202. 700
OTO= 70. 700 11TEI= 71. 400 12TEO=175. 800 13THUB= 81. 300
PR=1. 495 RPM=2194.  A-E=. 620 V-E=. 847 T-E=. 598

Y160: 19: 01: 38

OPO= 34. 352 01PEI= 24. 863 02PEO= 37. 200 03DELP=  1. 127 04TORQ= 13. 664
06EXC10V=  9. 986 RPM= 2195.  14TROT1=167. 100 15TROT2=252 700
OTO= 70. 600 11TEI= 71. 400 12TEO=175. 700 13THUB= 81. 200
PR=1. 496 RPM=2195.  A-E=. 622 V-E=. 850 T-E=. 600

Y160: 19: 04. 45

OPO= 36. 973 01PEI= 24. 772 02PEO= 39. 632 03DELP=  . 990 04TORQ= 14. 982
06EXC10V=  9. 983 RPM= 2193.  14TROT1=185. 900 15TROT2=230. 800
OTO= 70. 800 11TEI= 73. 100 12TEO=185. 900 13THUB= 81. 100
PR=1. 600 RPM=2193.  A-E=. 679 V-E= 837 T-E=. 632

Y160: 19: 05: 05

OPO= 37. 238 01PEI= 24. 872 02PEO= 39. 825 03DELP=  1. 002 04TORQ= 15. 080
06EXC10V=  9. 983 RPM= 2197.  14TROT1=173. 300 15TROT2=206. 200
OTO= 71. 000 11TEI= 74. 100 12TEO=186. 000 13THUB= 81. 200

PR=1. 601 RPM=2197  A-E=. 687 V-E=. 841 T-E=. 635

Y160: 19: 12: 55

OPO= 41. 385 01PEI= 25. 761 02PEO= 43. 772 03DELP=  . 925 04TORQ= 16. 991
06EXC10V=  9. 983 RPM= 2203.  14TROT1=174. 400 15TROT2=192. 500
OTO= 71. 700 11TEI= 73. 800 12TEO=196. 400 13THUB= 80. 900
PR=1. 699 RPM=2203.  A-E=. 701 V-E=. 823 T-E=. 648

Y160: 19: 13: 15

OPO= 41. 351 01PEI= 25. 730 02PEO= 43. 785 03DELP=  . 926 04TORQ= 16. 991
06EXC10V=  9. 984 RPM= 2206.  14TROT1=168. 600 15TROT2=184. 000
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Y160: 19: 15: 32

OPO= 43. 216 01PEI= 24. 928 02PEO= 45. 395 03DELP=    . 793 04TORQ= 18. 058
06EXC10V=  9. 984 RPM= 2201.  14TROT1=176. 000 15TROT2=162. 300
OTO= 71. 900 11TEI= 72. 600 12TEO=211. 500 13THUB= 80. 800
PR=1. 821 RPM=2201.  A-E=. 717 V-E=. 806 T-E=. 660

Y160: 19: 15: 52

OPO= 43. 311 01PEI= 25. 068 02PEO= 45. 480 03DELP=    . 797 04TORQ= 18. 075
06EXC10V=  9. 984 RPM= 2197.  14TROT1=177. 900 15TROT2=238. 900
OTO= 72. 300 11TEI= 69. 100 12TEO=211. 700 13THUB= 80. 800
PR=1. 814 RPM=2197.  A-E=. 689 V-E=. 800 T-E=. 655

Y160: 19: 20: 03

OPO= 49. 013 01PEI= 26. 774 02PEO= 51. 137 03DELP=    . 738 04TORQ= 20. 676
06EXC10V=  9. 983 RPM= 2188.  14TROT1=194. 300 15TROT2=231. 600
OTO= 72. 600 11TEI= 69. 100 12TEO=225. 900 13THUB= 80. 600
PR=1. 910 RPM=2188.  A-E=. 686 V-E=. 772 T-E=. 645

Y160: 19: 20: 23

OPO= 49. 268 01PEI= 26. 858 02PEO= 51. 382 03DELP=    . 738 04TORQ= 20. 756
06EXC10V=  9. 983 RPM= 2187.  14TROT1=202. 600 15TROT2=190. 200
OTO= 72. 600 11TEI= 71. 100 12TEO=226. 300 13THUB= 80. 500
PR=1. 913 RPM=2187.  A-E=. 697 V-E=. 775 T-E=. 649

Y160: 19: 23: 08

OPO= 53. 979 01PEI= 27. 570 02PEO= 55. 817 03DELP=    . 669 04TORQ= 23. 010
06EXC10V=  9. 983 RPM= 2169.  14TROT1=193. 000 15TROT2=250. 500
OTO= 73. 300 11TEI= 82. 300 12TEO=242. 900 13THUB= 80. 500
PR=2. 025 RPM=2169.  A-E=. 754 V-E=. 776 T-E=. 660

Y160: 19: 23: 28

OPO= 54. 185 01PEI= 27. 686 02PEO= 56. 016 03DELP=    . 666 04TORQ= 23. 106
06EXC10V=  9. 983 RPM= 2169.  14TROT1=211. 400 15TROT2=238. 300
OTO= 73. 400 11TEI= 73. 200 12TEO=243. 500 13THUB= 80. 500
```

10 June 1982

PR=1.455 RPM=2004. A-E=.834 V-E=.902 T-E=.596

Y000:16:27:20

OPO= 37.597 01PEI= 27.490 02PEO= 41.397 03DELP= 1.326 04TORQ= 15.408
06EXC10V= 9.994 RPM= 2195. 14TROT1=161.100 15TROT2=229.600
OTO= 70.800 11TEI= 71.100 12TEO=169.900 13THUB= 80.800
PR=1.506 RPM=2195. A-E=.667 V-E=.871 T-E=.613

Y000:16:27:36

OPO= 37.637 01PEI= 27.535 02PEO= 41.475 03DELP= 1.323 04TORQ= 15.457
06EXC10V= 9.994 RPM= 2197. 14TROT1=165.300 15TROT2=242.300
OTO= 70.800 11TEI= 71.000 12TEO=169.800 13THUB= 80.700
PR=1.506 RPM=2197. A-E=.668 V-E=.868 T-E=.610

Y000:16:31:21

OPO= 40.790 01PEI= 27.799 02PEO= 44.279 03DELP= 1.170 04TORQ= 16.825
06EXC10V= 9.994 RPM= 2190. 14TROT1=171.400 15TROT2=274.900
OTO= 71.300 11TEI= 71.500 12TEO=181.000 13THUB= 80.900
PR=1.593 RPM=2190. A-E=.691 V-E=.849 T-E=.634

Y000:16:31:37

OPO= 40.770 01PEI= 27.859 02PEO= 44.299 03DELP= 1.174 04TORQ= 16.813
06EXC10V= 9.994 RPM= 2191. 14TROT1=170.300 15TROT2=202.600
OTO= 71.300 11TEI= 71.600 12TEO=181.000 13THUB= 80.900

PR=1.590 RPM=2191. A-E=.689 V-E=.842 T-E=.633

Y000:17:06:09

OPO= 43.383 01PEI= 26.371 02PEO= 46.425 03DELP= .955 04TORQ= 18.416
06EXC10V= 9.994 RPM= 2203. 14TROT1=234.100 15TROT2=242.400
OTO= 72.000 11TEI= 72.000 12TEO=200.000 13THUB=145.000
PR=1.760 RPM=2203. A-E=.729 V-E=.833 T-E=.665

Y000:17:06:25

OPO= 43.453 01PEI= 26.442 02PEO= 46.543 03DELP= .960 04TORQ= 18.386
06EXC10V= 9.994 RPM= 2202. 14TROT1=255.000 15TROT2=274.200
OTO= 72.000 11TEI= 72.100 12TEO=200.300 13THUB=145.400

PR=1.760 RPM=2202. A-E=.728 V-E=.834 T-E=.669

Y000:17:08:10

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OTO= 72.200 11TEI= 72.300 12TEO=197.200 13THUB=148.700
PR=1.711 RPM=2204.  A-E=.707 V-E=.836 T-E=.656

Y000:17:08:26

OPO= 43.243 01PEI= 27.051 02PEO= 46.393 03DELP=  1.022 04TORQ= 18.110
06EXC10V=  9.994 RPM= 2202.  14TROT1=270.700 15TROT2=270.000
OTO= 72.300 11TEI= 72.400 12TEO=197.200 13THUB=149.100
PR=1.715 RPM=2202.  A-E=.711 V-E=.839 T-E=.664

Y000:17:11:14

OPO= 45.591 01PEI= 26.933 02PEO= 48.824 03DELP=   .939 04TORQ= 19.462
06EXC10V=  9.994 RPM= 2198.  14TROT1=231.000 15TROT2=317.200
OTO= 72.600 11TEI= 72.700 12TEO=207.400 13THUB=152.800
PR=1.813 RPM=2193.  A-E=.733 V-E=.833 T-E=.679

Y000:17:11:30

OPO= 45.451 01PEI= 26.868 02PEO= 48.524 03DELP=   .932 04TORQ= 19.403
06EXC10V=  9.994 RPM= 2198.  14TROT1=244.400 15TROT2=289.500
OTO= 72.600 11TEI= 72.600 12TEO=207.500 13THUB=153.200
PR=1.806 RPM=2198.  A-E=.727 V-E=.831 T-E=.673

Y000:17:14:05

OPO= 49.408 01PEI= 27.535 02PEO= 52.344 03DELP=   .831 04TORQ= 21.247
06EXC10V=  9.994 RPM= 2187.  14TROT1=257.800 15TROT2=284.800
OTO= 73.200 11TEI= 73.000 12TEO=220.800 13THUB=156.700
PR=1.[illegible]90 RPM=2187.  A-E=.727 V-E=.805 T-E=.668

Y000:17:14:21

OPO= 49.433 01PEI= 27.532 02PEO= 52.374 03DELP=   .833 04TORQ= 21.241
06EXC10V=  9.994 RPM= 2187   14TROT1=248.000 15TROT2=320.900
OTO= 73.200 11TEI= 73.000 12TEO=221.200 13THUB=157.100
PR=1.902 RPM=2187.  A-E=.726 V-E=.806 T-E=.669

Y000:17:18:28

OPO= 53.495 01PEI= 27.825 02PEO= 56.506 03DELP=   .782 04TORQ= 23.333
06EXC10V=  9.994 RPM= 2195   14TROT1=260.800 15TROT2=182.800
OTO= 74.600 11TEI= 74.200 12TEO=236.800 13THUB=163.800
PR=2.031 RPM=2195.  A-E=.737 V-E=.804 T-E=.684

Y000:17:18:44

OPO= 53.745 01PEI= 27.900 02PEO= 56.566 03DELP=   .779 04TORQ= 23.[illegible]41
06EXC10V=  9.994 RPM= 2196.  14TROT1=244.900 15TROT2=179.500
OTO= 74.800 11TEI= 74.300 12TEO=237.100 13THUB=164.300
PR=2.027 RPM=2196.  A-E=.735 V-E=.801 T-E=.681

Y000:17:21:36

OPO= 55.643 01PEI= 28.002 02PEO= 58.267 03DELP=   .722 04TORQ= 24.314
06EXC10V=  9.995 RPM= 2193.  14TROT1=223.900 15TROT2=216.800
OTO= 75.400 11TEI= 74.900 12TEO=247.500 13THUB=169.400
PR=2.081 RPM=2193.  A-E=.722 V-E=.784 T-E=.668

Y000:17:21:52

OPO= 55.[illegible]68 01PEI= 27.796 02PEO= 58.019 03DELP=   .720 04TORQ= 24.160
06EXC10V=  9.995 RPM= 2193.  14TROT1=224.400 15TROT2=224.300
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OPO= 60.340 01PEI= 28.170 02PEO= 62.650 03DELP=   .633 04TORQ= 26.490
06EXC10V=  9.994 RPM= 2182.  14TROT1=231.900 15TROT2=222.500
OTO= 76.000 11TEI= 75.500 12TEO=263.800 13THUB=173.100
PR=2.224 RPM=2182.  A-E=.730 V-E=.766 T-E=.664

Y000: 17:23:43

OPO= 60.389 01PEI= 28.217 02PEO= 62.649 03DELP=   .634 04TORQ= 26.550
06EXC10V=  9.995 RPM= 2180.  14TROT1=224.700 15TROT2=210.900
OTO= 76.200 11TEI= 75.600 12TEO=264.400 13THUB=173.500
PR=2.220 RPM=2180.  A-E=.726 V-E=.766 T-E=.662

Y000: 17:25:52

OPO= 59.025 01PEI= 30.386 02PEO= 61.748 03DELP=   .791 04TORQ= 25.466
06EXC10V=  9.995 RPM= 2187.  14TROT1=234.100 15TROT2=222.000
OTO= 76.800 11TEI= 76.200 12TEO=249.700 13THUB=177.400
PR=2.032 RPM=2187.  A-E=.694 V-E=.782 T-E=.666

Y000: 17:26:06

OPO= 59.040 01PEI= 30.313 02PEO= 61.676 03DELP=   .789 04TORQ= 25.482
06EXC10V=  9.995 RPM= 2189.  14TROT1=225.900 15TROT2=219.000
OTO= 76.800 11TEI= 76.200 12TEO=249.600 13THUB=177.800
PR=2.035 RPM=2189.  A-E=.696 V-E=.782 T-E=.665

Y000: 17:29:37

OPO= 52.131 01PEI= 29.295 02PEO= 55.378 03DELP=   .905 04TORQ= 22.383
06EXC10V=  9.994 RPM= 2213.  14TROT1=218.000 15TROT2=199.800
OTO= 75.900 11TEI= 75.900 12TEO=231.400 13THUB=181.700
PR=1.890 RPM=2213.  A-E=.688 V-E=.803 T-E=.667

Y000: 17:29:53

OPO= 52.056 01PEI= 29.214 02PEO= 55.350 03DELP=   .907 04TORQ= 22.371
06EXC10V=  9.995 RPM= 2210.  14TROT1=207.900 15TROT2=186.900
OTO= 75.900 11TEI= 75.700 12TEO=231.200 13THUB=182.000
```

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PR=1.895 RPM=2210. A-E=.690 V-E=.806 T-E=.671

Y000:17:35:24

OPO= 42.110 01PEI= 27.027 02PEO= 44.600 03DELP= .629 04TORQ= 16.862
06EXC10V= 9.995 RPM= 1797. 14TROT1=212.900 15TROT2=145.600
OTO= 72.700 11TEI= 73.400 12TEO=202.100 13THUB=178.000
PR=1.650 RPM=1797. A-E=.638 V-E=.802 T-E=.629

Y000:17:35:40

OPO= 42.119 01PEI= 27.006 02PEO= 44.592 03DELP= .629 04TORQ= 16.905
06EXC10V= 9.994 RPM= 1799. 14TROT1=190.000 15TROT2=138.100
OTO= 72.600 11TEI= 73.300 12TEO=201.900 13THUB=177.500

PR=1.651 RPM=1799. A-E=.639 V-E=.802 T-E=.627

Y000:17:39:11

OPO= 42.080 01PEI= 27.015 02PEO= 44.387 03DELP= .633 04TORQ= 16.827
06EXC10V= 9.995 RPM= 1799. 14TROT1=173.300 15TROT2=134.100
OTO= 71.800 11TEI= 72.300 12TEO=198.300 13THUB=172.200
PR=1.643 RPM=1799. A-E=.644 V-E=.803 T-E=.625

Y000:17:39:27

OPO= 42.145 01PEI= 27.088 02PEO= 44.430 03DELP= .633 04TORQ= 16.831
06EXC10V= 9.995 RPM= 1797. 14TROT1=172.300 15TROT2=131.300
OTO= 71.800 11TEI= 72.300 12TEO=198.100 13THUB=171.900

PR=1.640 RPM=1797. A-E=.643 V-E=.803 T-E=.623

Y000:17:45:39

OPO= 41.968 01PEI= 26.913 02PEO= 44.213 03DELP= .630 04TORQ= 16.717
06EXC10V= 9.993 RPM= 1796. 14TROT1=162.600 15TROT2=120.500
OTO= 71.500 11TEI= 71.900 12TEO=195.200 13THUB=164.500
PR=1.643 RPM=1796. A-E=.656 V-E=.804 T-E=.627

Y000:17:45:55

OPO= 41.983 01PEI= 26.875 02PEO= 44.263 03DELP= .629 04TORQ= 16.701
06EXC10V= 9.993 RPM= 1796. 14TROT1=162.900 15TROT2=107.800
OTO= 71.500 11TEI= 71.900 12TEO=195.300 13THUB=164.300

PR=1.647 RPM=1796. A-E=.661 V-E=.805 T-E=.631

Y000:17:52:31

OPO= 42.074 01PEI= 26.940 02PEO= 44.382 03DELP= .631 04TORQ= 16.743
06EXC10V= 9.994 RPM= 1800. 14TROT1=166.900 15TROT2=118.900

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Y000: 17: 52: 47

OPO= 42. 139 01PEI= 26. 951 02PEO= 44. 439 03DELP=    . 631 04TORQ= 16. 796
06EXC10V=  9. 994 RFM= 1799.  14TROT1=161. 500 15TROT2=128. 100
OTO= 71. 600 11TEI= 72. 000 12TEO=193. 900 13THUB=159. 000
PR=1. 649 RPM=1799.  A-E=. 671 V-E=. 804 T-E=. 630

Y000: 17: 57: 58

OPO= 42. 198 01PEI= 27. 048 02PEO= 44. 579 03DELP=    . 635 04TORQ= 16. 895
06EXC10V=  9. 993 RPM= 1800.  14TROT1=176. 700 15TROT2= 79. 500
OTO= 71. 500 11TEI= 71. 900 12TEO=193. 600 13THUB=156. 300
PR=1. 648 RPM=1800.  A-E=. 671 V-E=. 804 T-E=. 627

Y000: 17: 58: 14

OPO= 42. 258 01PEI= 27. 037 02PEO= 44. 594 03DELP=    . 633 04TORQ= 16. 891
06EXC10V=  9. 993 RPM= 1801.  14TROT1=158. 000 15TROT2= 95. 700
OTO= 71. 600 11TEI= 71. 900 12TEO=193. 500 13THUB=156. 200
PR=1. 649 RPM=1801.  A-E=. 679 V-E=. 803 T-E=. 628

Y000: 18: 03: 35

OPO= 42. 143 01PEI= 27. 078 02PEO= 44. 474 03DELP=    . 629 04TORQ= 16. 760
06EXC10V=  9. 993 RPM= 1800.  14TROT1=162. 900 15TROT2=166. 500
OTO= 71. 900 11TEI= 72. 200 12TEO=193. 000 13THUB=154. 500
PR=1. 642 RPM=1800.  A-E=. 671 V-E=. 799 T-E=. 625

Y000: 18: 03: 51

OPO= 42. 126 01PEI= 27. 141 02PEO= 44. 439 03DELP=    . 630 04TORQ= 16. 770
06EXC10V=  9. 993 RPM= 1800.  14TROT1=156. 900 15TROT2=161. 400
OTO= 71. 700 11TEI= 72. 100 12TEO=192. 900 13THUB=154. 300
PR=1. 637 RPM=1800.  A-E=. 667 V-E=. 797 T-E=. 620

Y000: 18: 09: 49

OPO= 41. 823 01PEI= 27. 043 02PEO= 44. 123 03DELP=    . 625 04TORQ= 16. 641
06EXC10V=  9. 993 RPM= 1799.  14TROT1=165. 100 15TROT2=127. 700
OTO= 71. 900 11TEI= 72. 200 12TEO=192. 800 13THUB=153. 700
PR=1. 632 RPM=1799.  A-E=. 665 V-E=. 794 T-E=. 616

Y000: 18: 10: 05

OPO= 41. 518 01PEI= 27. 006 02PEO= 44. 138 03DELP=    . 624 04TORQ= 16. 576
06EXC10V=  9. 993 RPM= 1799.  14TROT1=160. 500 15TROT2=138. 000
OTO= 71. 900 11TEI= 72. 200 12TEO=192. 800 13THUB=153. 700
PR=1. 634 RPM=1799.  A-E=. 665 V-E=. 795 T-E=. 620

Y000: 18: 16: 17

OPO= 41. 553 01PEI= 26. 958 02PEO= 43. 843 03DELP=    . 641 04TORQ= 16. 419
06EXC10V=  9. 992 RPM= 1800.  14TROT1=236. 000 15TROT2=175. 800
OTO= 72. 000 11TEI= 72. 400 12TEO=192. 600 13THUB=153. 300
PR=1. 626 RPM=1800.  A-E=. 661 V-E=. 804 T-E=. 626

Y000: 18: 16: 33

OPO= 41. 559 01PEI= 26. 914 02PEO= 43. 853 03DELP=    . 643 04TORQ= 16. 425
06EXC10V=  9. 992 RPM= 1801.  14TROT1=168. 000 15TROT2=182. 100
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Y000: 18: 21: 47

OPO= 41. 944 01PEI= 26. 993 02PEO= 43. 591 03DELP=    . 632 04TORQ= 16. 198
06EXC10V=  9. 993 RPM= 1803.  14TROT1=159. 500 15TROT2=188. 500
OTO= 72. 200 11TEI= 72. 500 12TEO=192. 700 13THUB=153. 800
PR=1. 618 RPM=1803.  A-E=. 654 V-E=. 796 T-E=. 620

Y000: 18: 22: 03

OPO= 41. 358 01PEI= 26. 990 02PEO= 43. 592 03DELP=    . 631 04TORQ= 16. 276
06EXC10V=  9. 992 RPM= 1804.  14TROT1=162. 300 15TROT2=178. 000
OTO= 72. 200 11TEI= 72. 500 12TEO=192. 700 13THUB=154. 000

PR=1. 615 RPM=1804.  A-E=. 651 V-E=. 793 T-E=. 614

Y000: 18: 24: 36

OPO= 42. 177 01PEI= 26. 886 02PEO= 44. 476 03DELP=    . 662 04TORQ= 16. 793
06EXC10V=  9. 992 RPM= 1799.  14TROT1=174. 000 15TROT2=245. 800
OTO= 72. 400 11TEI= 72. 600 12TEO=193. 300 13THUB=153. 300
PR=1. 654 RPM=1799.  A-E=. 683 V-E=. 826 T-E=. 650

Y000: 18: 24: 52

OPO= 42. 167 01PEI= 26. 876 02PEO= 44. 446 03DELP=    . 663 04TORQ= 16. 815
06EXC10V=  9. 992 RPM= 1799.  14TROT1=172. 300 15TROT2=221. 700
OTO= 72. 300 11TEI= 72. 600 12TEO=193. 400 13THUB=153. 300

PR=1. 654 RPM=1799.  A-E=. 682 V-E=. 827 T-E=. 649

Y000: 18: 27: 20

OPO= 42. 891 01PEI= 27. 034 02PEO= 45. 291 03DELP=    . 682 04TORQ= 17. 289
06EXC10V=  9. 991 RPM= 1795.  14TROT1=166. 200 15TROT2=253. 600
OTO= 72. 000 11TEI= 72. 400 12TEO=193. 600 13THUB=152. 400
PR=1. 675 RPM=1795.  A-E=. 696 V-E=. 843 T-E=. 665

Y000: 18: 27: 36

OPO= 42. 891 01PEI= 27. 028 02PEO= 45. 318 03DELP=    . 685 04TORQ= 17. 334
06EXC10V=  9. 991 RPM= 1797.  14TROT1=184. 200 15TROT2=259. 300
OTO= 72. 000 11TEI= 72. 400 12TEO=193. 600 13THUB=152. 300

PR=1. 677 RPM=1797.  A-E=. 699 V-E=. 844 T-E=. 665

Y000: 18: 29: 56

OPO= 43. 031 01PEI= 27. 068 02PEO= 45. 516 03DELP=    . 685 04TORQ= 17. 443
06EXC10V=  9. 991 RPM= 1798.  14TROT1=169. 300 15TROT2=264. 000
OTO= 71. 300 11TEI= 71. 800 12TEO=193. 200 13THUB=151. 400

PR=1. 682 RPM=1798.  A-E=. 702 V-E=. 843 T-E=. 666

Y000: 18: 30: 12

OPO= 42. 932 01PEI= 27. 269 02PEO= 45. 419 03DELP=    . 678 04TORQ= 17. 236
06EXC10V=  9. 992 RPM= 1796.  14TROT1=160. 200 15TROT2=249. 400
OTO= 71. 200 11TEI= 71. 700 12TEO=192. 900 13THUB=151. 200
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Y162:16:47:15

OPO= 32.014 01PEI= 26.667 02PEO= 34.434 03DELP=   .615 04TORQ= 10.432
06EXC10V= 10.004 RPM= 1502.  14TROT1=207.200 15TROT2= 69.600
OTO= 68.900 11TEI= 69.600 12TEO=133.100 13THUB=105.700
PR=1.291 RPM=1502.  A-E=.586 V-E=.832 T-E=.512

Y162:16:47:31

OPO= 32.022 01PEI= 26.641 02PEO= 34.442 03DELP=   .621 04TORQ= 10.497
06EXC10V= 10.003 RPM= 1501.  14TROT1=247.400 15TROT2= 98.600
OTO= 68.900 11TEI= 69.600 12TEO=138.300 13THU3=106.300
PR=1.293 RPM=1501  A-E=.587 V-E=.637 T-E=.514

Y162:17:16:05
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OTO= 71.400 11TEI= 71.600 12TEO=172.500 13THUB=152.200
PR=1.508 RPM=2115. A-E=.656 V-E=.864 T-E=.612

Y162:17:16:21

OPO= 37.058 01PEI= 27.208 02PEO= 41.185 03DELP= 1.213 04TORQ= 15.347
06EXC10V= 10.006 RPM= 2114. 14TROT1=152.800 15TROT2=345.000
OTO= 71.400 11TEI= 71.600 12TEO=172.500 13THUB=152.600
PR=1.514 RPM=2114. A-E=.663 V-E=.869 T-E=.616

Y162:17:22:27

OPO= 37.846 01PEI= 27.391 02PEO= 41.633 03DELP= 1.289 04TORQ= 15.707
06EXC10V= 10.006 RPM= 2192. 14TROT1=152.600 15TROT2=326.900
OTO= 71.900 11TEI= 72.200 12TEO=176.200 13THUB=159.000
PR=1.520 RPM=2192. A-E=.651 V-E=.867 T-E=.611

Y162:17:22:43

OPO= 37.926 01PEI= 27.392 02PEO= 41.710 03DELP= 1.298 04TORQ= 15.768
06EXC10V= 10.006 RPM= 2192. 14TROT1=152.900 15TROT2=286.400
OTO= 71.900 11TEI= 72.200 12TEO=176.300 13THUB=159.100
PR=1.523 RPM=2192. A-E=.653 V-E=.871 T-E=.614

Y162:17:27:02

OPO= 41.270 01PEI= 27.850 02PEO= 44.893 03DELP= 1.163 04TORQ= 17.292
06EXC10V= 10.006 RPM= 2182. 14TROT1=165.600 15TROT2=206.100
OTO= 72.000 11TEI= 72.100 12TEO=186.500 13THUB=162.900
PR=1.612 RPM=2182. A-E=.680 V-E=.854 T-E=.639

Y162:17:27:18

OPO= 41.241 01PEI= 27.876 02PEO= 44.911 03DELP= 1.171 04TORQ= 17.265
06EXC10V= 10.007 RPM= 2183. 14TROT1=161.400 15TROT2=209.600
OTO= 72.100 11TEI= 72.200 12TEO=186.700 13THUB=163.400

PR=1.611 RPM=2183. A-E=.679 V-E=.855 T-E=.641

Y162:17:31:06

OPO= 41.415 01PEI= 27.893 02PEO= 45.073 03DELP= 1.175 04TORQ= 17.364
06EXC10V= 10.006 RPM= 2187. 14TROT1=161.300 15TROT2= 80.400
OTO= 72.200 11TEI= 72.300 12TEO=187.700 13THUB=166.300
PR=1.616 RPM=2187. A-E=.678 V-E=.856 T-E=.643

Y162:17:31:22

OPO= 41.410 01PEI= 27.958 02PEO= 45.151 03DELP= 1.179 04TORQ= 17.417
06EXC10V= 10.007 RPM= 2190. 14TROT1=162.000 15TROT2=115.400
OTO= 72.100 11TEI= 72.200 12TEO=187.600 13THUB=166.600

PR=1.615 RPM=2190. A-E=.677 V-E=.855 T-E=.640

Y162:17:35:35

OPO= 44.419 01PEI= 28.243 02PEO= 47.381 03DELP= 1.095 04TORQ= 18.830
06EXC10V= 10.006 RPM= 2196. 14TROT1=166.100 15TROT2=108.200
OTO= 72.500 11TEI= 72.400 12TEO=198.100 13THUB=169.300
PR=1.695 RPM=2196. A-E=.690 V-E=.844 T-E=.655

Y162:17:35:51

[illegible]
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PR=1.696 RPM=2196. A-E=.690 V-E=.842 T-E=.653

Y162:17:41:35

~~OPO= 47.723 01PEI= 28.596 02PEO= 51.242 03DELP= .990 04TORQ= 20.656~~
06EXC10V= 10.007 RPM= 2190. 14TROT1=176.000 15TROT2=172.900
OTO= 73.200 11TEI= 73.100 12TEO=211.200 13THUB=174.000
~~PR=1.792 RPM=2190. A-E=.700 V-E=.828 T-E=.660~~

Y162:17:41:51

OPO= 47.718 01PEI= 28.627 02PEO= 51.239 03DELP= .982 04TORQ= 20.656
06EXC10V= 10.007 RPM= 2190. 14TROT1=175.100 15TROT2=161.900
~~OTO= 73.200 11TEI= 73.100 12TEO=211.300 13THUB=174.200~~
PR=1.790 RPM=2190. A-E=.698 V-E=.824 T-E=.657

~~Y162:17:47:06~~

OPO= 51.545 01PEI= 28.614 02PEO= 54.731 03DELP= .896 04TORQ= 22.665
~~06EXC10V= 10.008 RPM= 2207. 14TROT1=186.400~~ 15TROT2=160.400
OTO= 74.800 11TEI= 74.400 12TEO=229.400 13THUB=181.100
PR=1.913 RPM=2207. A-E=.702 V-E=.814 T-E=.665

Y162:17:47:22

~~OPO= 51.265 01PEI= 28.443~~ 02PEO= 54.454 03DELP= .869 04TORQ= 22.589
06EXC10V= 10.008 RPM= 2209 14TROT1=186.500 15TROT2=159.600
OTO= 74.800 11TEI= 74.400 12TEO=229.400 13THUB=181.400
~~PR=1.915 RPM=2209. A-E=.703~~ V-E=.813 T-E=.663

Y162:17:52:08

OPO= 56.334 01PEI= 29.684 02PEO= 59.300 03DELP= .837 04TORQ= 24.823
06EXC10V= 10.008 RPM= 2194. 14TROT1=196.700 15TROT2=183.700
~~OTO= 76.400 11TEI= 75.900 12TEO=244.700~~ 13THUB=188.500
PR=1.998 RPM=2194 A-E=.694 V-E=.800 T-E=.665

~~Y162:17:52:24~~

OPO= 56.314 01PEI= 29.605 02PEO= 59.313 03DELP= .842 04TORQ= 24.891
~~06EXC10V= 10.008 RPM= 2195 14TROT1=199.000 15TROT2=223.900~~
OTO= 76.400 11TEI= 75.900 12TEO=244.800 13THUB=189.000
PR=2.003 RPM=2195 A-E=.697 V-E=.805 T-E=.668

Y162:17:58:19

~~OPO= 59.813 01PEI= 29.555 02PEO= 62.719~~ 03DELP= .754 04TORQ= 26.747
06EXC10V= 10.007 RPM= 2201. 14TROT1=214.800 15TROT2=244.400
OTO= 77.800 11TEI= 77.100 12TEO=263.200 13THUB=199.700
~~PR=2.122 RPM=2201. A-E=.695 V-E=.786~~ T-E=.662

Y162:17:58:35

OPO= 59.807 01PEI= 29.552 02PEO= 62.665 03DELP= .753 04TORQ= 26.744
06EXC10V= 10.008 RPM= 2201. 14TROT1=213.500 15TROT2=264.100
OTO= 77.800 11TEI= 77.100 12TEO=263.400 13THUB=200.300

PR=2.120 RPM=2201 A-E=.691 V-E=.785 T-E=.661

OPO= 58.086 01PEI= 27.390 02PEO= 60.582 03DELP= .680 04TORQ= 26.505
06EXC10V= 10.008 RPM= 2216. 14TROT1=222.400 15TROT2=233.800
~~OTO= 78.100 11TEI= 77.600 12TEO=274.800 13THUB=211.300~~
PR=2.212 RPM=2216. A-E=.694 V-E=.789 T-E=.660

~~Y162:18:05:35~~

OPO= 58.066 01PEI= 27.435 02PEO= 60.569 03DELP= .677 04TORQ= 26.541
~~06EXC10V= 10.008 RPM= 2214. 14TROT1=223.100 15TROT2=250.800~~
OTO= 78.200 11TEI= 77.600 12TEO=275.000 13THUB=211.600

PR=2.208 RPM=2214. A-E=.692 V-E=.787 T-E=.656

Y162:18:22:01

OPO= 47.583 01PEI= 25.931 02PEO= 50.659 03DELP= .853 04TORQ= 21.174
06EXC10V= 10.008 RPM= 2255. 14TROT1=217.600 15TROT2=318.700
OTO= 99.000 11TEI= 97.200 12TEO=259.900 13THUB=212.500
PR=1.954 RPM=2255 A-E=.723 V-E=.831 T-E=.682

Y162:18:22:17

OPO= 47.448 01PEI= 25.888 02PEO= 50.532 03DELP= .844 04TORQ= 21.070
06EXC10V= 10.008 RPM= 2255. 14TROT1=218.300 15TROT2=370.000
OTO= 99.300 11TEI= 97.500 12TEO=260.200 13THUB=212.700
PR=1.952 RPM=2255. A-E=.722 V-E=.827 T-E=.680

Y162:18:24:42

OPO= 46.939 01PEI= 24.956 02PEO= 49.760 03DELP= .844 04TORQ= 21.039
06EXC10V= 10.008 RPM= 2327. 14TROT1=222.600 15TROT2=391.500
OTO=101.800 11TEI=100.000 12TEO=267.600 13THUB=213.800
PR=1.994 RPM=2327 A-E=.729 V-E=.826 T-E=.679

Y162:18:24:58

OPO= 46.865 01PEI= 24.891 02PEO= 49.650 03DELP= .853 04TORQ= 21.020
06EXC10V= 10.008 RPM= 2326 14TROT1=222.300 15TROT2=347.900
OTO=102.000 11TEI=100.200 12TEO=263.000 13THUB=214.000
PR=1.995 RPM=2326 A-E=.729 V-E=.833 T-E=.684

Y162:18:30:54

OPO= 46.830 01PEI= 24.106 02PEO= 49.728 03DELP= .851 04TORQ= 21.125
06EXC10V= 10.009 RPM= 2421. 14TROT1=243.100 15TROT2=275.500
OTO=116.800 11TEI=114.800 12TEO=289.700 13THUB=219.600
PR=2.063 RPM=2421. A-E=.756 V-E=.854 T-E=.712

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OTO=142.500 11TEI=134.500 12TEO=305.400 13THUB=222.900
PR=2.058 RPM=2422. A-E=.797 V-E=.872 T-E=.731

Y162:18:33:41

OPO= 46.560 01PEI= 23.990 02PEO= 49.378 03DELP=  .862 04TORQ= 21.031
06EXC10V= 10.008 RPM= 2423.  14TROT1=268.300 15TROT2=217.400
OTO=132.900 11TEI=131.300 12TEO=304.000 13THUB=223.700
PR=2.058 RPM=2423. A-E=.785 V-E=.874 T-E=.726

Y162:18:38:33

OPO= 43.865 01PEI= 24.885 02PEO= 47.025 03DELP=  1.090 04TORQ= 19.650
06EXC10V= 10.007 RPM= 2514.  14TROT1=273.100 15TROT2=262.300
OTO=135.900 11TEI=134.700 12TEO=290.600 13THUB=231.200

PR=1.890 RPM=2514. A-E=.761 V-E=.885 T-E=.710

Y162:18:38:52

OPO= 43.656 01PEI= 24.747 02PEO= 46.797 03DELP=  1.076 04TORQ= 19.533
06EXC10V= 10.007 RPM= 2511.  14TROT1=284.600 15TROT2=258.300
OTO=133.000 11TEI=133.100 12TEO=289.700 13THUB=231.200
PR=1.891 RPM=2511. A-E=.757 V-E=.883 T-E=.710

Y162:18:50:35

OPO= 32.371 01PEI= 26.029 02PEO= 37.405 03DELP=  1.983 04TORQ= 14.407
06EXC10V= 10.009 RPM= 2547.  14TROT1=234.000 15TROT2=198.600
OTO= 75.500 11TEI= 76.400 12TEO=182.500 13THUB=228.500
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Y167:18:53:20

OPO= 45.321 01PEI= 27.632 02PEO= 47.801 03DELP= .790 04TORQ= 18.975
06EXC10V= 10.005 RPM= 2010. 14TROT1=185.500 15TROT2=167.500
OTO= 98.400 11TEI= 97.200 12TEO=226.500 13THUB=152.100
PR=1.730 RPM=2010. A-E=.731 V-E=.822 T-E=.645

Y167:18:53:50

OPO= 45.366 01PEI= 27.617 02PEO= 47.851 03DELP= .791 04TORQ= 19.071
06EXC10V= 10.005 RPM= 2012. 14TROT1=182.800 15TROT2=164.000
OTO= 98.400 11TEI= 97.200 12TEO=227.100 13THUB=153.400
PR=1.733 RPM=2012. A-E=.730 V-E=.822 T-E=.644

Y167:19:00:47

OPO= 45.381 01PEI= 27.771 02PEO= 47.976 03DELP= .795 04TORQ= 18.993
06EXC10V= 10.005 RPM= 2023. 14TROT1=234.300 15TROT2=190.200
OTO=112.200 11TEI=111.500 12TEO=246.000 13THUB=171.800
PR=1.724 RPM=2023. A-E=.716 V-E=.835 T-E=.657

Y167:19:01:17

OPO= 45.666 01PEI= 27.982 02PEO= 48.181 03DELP= .796 04TORQ= 18.914
06EXC10V= 10.005 RPM= 2019. 14TROT1=236.700 15TROT2=190.800
OTO=116.700 11TEI=113.200 12TEO=246.900 13THUB=173.400

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Y168: 10: 10: 06

OPO= 49. 219 01PEI= 27. 688 02PEO= 51. 494 03DELP=    . 673 04TORQ= 21. 147
06EXC10V= 10. 004 RPM= 2015.  14TROT1=305. 000 15TROT2=176. 800
OTO=119. 800 11TEI=116. 400 12TEO=271. 300 13THUB=191. 300
PR=1. 860 RPM=2015.  A-E=. 722 V-E=. 818 T-E=. 660

Y168: 10: 10: 36

OPO= 49. 159 01PEI= 27. 728 02PEO= 51. 429 03DELP=    . 670 04TORQ= 21. 069
06EXC10V= 10. 004 RPM= 2014.  14TROT1=283. 900 15TROT2=179. 000
OTO=120. 300 11TEI=117. 000 12TEO=272. 100 13THUB=192. 400
PR=1. 855 RPM=2014.  A-E=. 719 V-E=. 815 T-E=. 656

Y168: 10: 17: 16

OPO= 51. 141 01PEI= 27. 639 02PEO= 53. 754 03DELP=    . 725 04TORQ= 22. 496
06EXC10V= 10. 004 RPM= 2112.  14TROT1=256. 800 15TROT2=205. 300
OTO=129. 800 11TEI=126. 500 12TEO=293. 000 13THUB=209. 300
PR=1. 945 RPM=2112.  A-E=. 738 V-E=. 834 T-E=. 682

Y168: 10: 17: 46

OPO= 51. 216 01PEI= 27. 604 02PEO= 53. 858 03DELP=    . 730 04TORQ= 22. 468
06EXC10V= 10. 004 RPM= 2112.  14TROT1=270. 200 15TROT2=191. 100
OTO=130. 300 11TEI=127. 000 12TEO=294. 000 13THUB=210. 500
PR=1. 951 RPM=2112.  A-E= 740 V-E=. 838 T-E=. 689

Y168: 10: 20: 23

OPO= 53. 122 01PEI= 27. 626 02PEO= 55. 793 03DELP=    . 760 04TORQ= 23. 705
06EXC10V= 10 004 RPM= 2213.  14TROT1=248 000 15TROT2=244. 400
OTO=133. 600 11TEI=130 000 12TEO=306. 500 13THUB=216. 300
PR=2. 020 RPM=2213.  A-E=. 744 V-E=. 833 T-E=. 686

Y168: 10: 20: 53

OPO= 53. 167 01PEI= 27. 625 02PEO= 55. 833 03DELP=    . 759 04TORQ= 23. 739
06EXC10V= 10. 004 RPM= 2213.  14TROT1=247. 000 15TROT2=245 400
OTO=134. 200 11TEI=130. 600 12TEO=307. 400 13THUB=217. 700
PR=2. 021 RPM=2213.  A-E=. 744 V-E=. 833 T-E=. 686

Y168: 10: 27: 15

OPO= 49. 668 01PEI= 26. 990 02PEO= 52. 916 03DELP=    . 890 04TORQ= 22. 196
06EXC10V= 10. 004 RPM= 2338.  14TROT1=254 400 15TROT2=253 900
OTO=139. 400 11TEI=136. 100 12TEO=306. 200 13THUB=231. 600
PR=1. 961 RPM=2338.  A-E=. 744 V-E=. 847 T-E=. 694

Y168: 10: 27: 45

OPO= 49. 539 01PEI= 26. 878 02PEO= 52. 781 03DELP=    . 890 04TORQ= 22. 173
06EYC10V= 10. 004 RPM= 2337  14TROT1=255. 100 15TROT2=251. 900
OTO=139. 700 11TEI=136. 300 12TEO=306. 800 13THUB=232. 500
PR=1. 964 RPM=2337.  A-E=. 744 V-E=. 850 T-E=. 696
```

```
OPO= 45.341 O1PEI= 26.619 02PEO= 48.783 03DELP=  1.180 04TORQ= 20.051
06EXC10V= 10.005 RPM= 2517.  14TROT1=256.800 15TROT2=253.500
OTO=144.400 11TEI=140.900 12TEO=295.700 13THUB=240.400
PR=1.833 RPM=2517.  A-E=.734 V-E=.876 T-E=.699

Y168:10:33:09

OPO= 45.077 O1PEI= 26.528 02PEO= 48.358 03DELP=  1.169 04TORQ= 19.777
06EXC10V= 10.005 RPM= 2516.  14TROT1=256.600 15TROT2=252.900
OTO=144.600 11TEI=141.100 12TEO=295.700 13THUB=241.200
PR=1.823 RPM=2516.  A-E=.726 V-E=.873 T-E=.697

Y168:10:41:06

OPO= 47.028 O1PEI= 26.831 02PEO= 50.652 03DELP=  1.260 04TORQ= 21.045
06EXC10V= 10.005 RPM= 2617.  14TROT1=258.400 15TROT2=255.600
OTO=143.700 11TEI=140.100 12TEO=299.000 13THUB=246.800
PR=1.882 RPM=2617.  A-E=.752 V-E=.878 T-E=.709

Y168:10:41:20

OPO= 47.008 O1PEI= 26.790 02PEO= 50.502 03DELP=  1.249 04TORQ= 20.946
06EXC10V= 10.005 RPM= 2612.  14TROT1=259.000 15TROT2=256.700
OTO=144.200 11TEI=140.500 12TEO=299.200 13THUB=247.000
PR=1.885 RPM=2612.  A-E=.752 V-E=.878 T-E=.709

Y168:10:41:48

OPO= 47.148 O1PEI= 26.875 02PEO= 50.760 03DELP=  1.262 04TORQ= 20.975
06EXC10V= 10.005 RPM= 2611.  14TROT1=259.400 15TROT2=258.900
OTO=145.000 11TEI=141.200 12TEO=299.800 13THUB=247.600
PR=1.889 RPM=2611.  A-E=.756 V-E=.882 T-E=.715

Y168:10:42:04

OPO= 47.128 O1PEI= 26.944 02PEO= 50.610 03DELP=  1.258 04TORQ= 20.899
06EXC10V= 10.005 RPM= 2614.  14TROT1=260.100 15TROT2=256.100
OTO=145.500 11TEI=141.600 12TEO=300.500 13THUB=248.000
PR=1.878 RPM=2614.  A-E=.748 V-E=.877 T-E=.709

Y168:10:42:19

OPO= 47.123 O1PEI= 26.895 02PEO= 50.717 03DELP=  1.259 04TORQ= 20.926
06EXC10V= 10.006 RPM= 2622.  14TROT1=260.600 15TROT2=257.800
OTO=145.900 11TEI=142.100 12TEO=301.000 13THUB=248.200
PR=1.886 RPM=2622.  A-E=.753 V-E=.877 T-E=.712

Y168:10:42:36

OPO= 47.103 O1PEI= 26.937 02PEO= 50.587 03DELP=  1.253 04TORQ= 20.971
06EXC10V= 10.005 RPM= 2617.  14TROT1=260.600 15TROT2=254.000
OTO=146.300 11TEI=142.500 12TEO=301.400 13THUB=248.500
PR=1.879 RPM=2617.  A-E=.749 V-E=.875 T-E=.705

Y168:10:42:51

OPO= 47.009 O1PEI= 26.908 02PEO= 50.602 03DELP=  1.256 04TORQ= 20.949
06EXC10V= 10.006 RPM= 2616.  14TROT1=261.200 15TROT2=257.400
OTO=146.600 11TEI=142.800 12TEO=301.900 13THUB=248.900
PR=1.881 RPM=2616.  A-E=.750 V-E=.877 T-E=.708

Y168:10:43:05
```

PR=1.839 RPM=2613. A-E=.741 V-E=.892 T-E=.718

Y168:10:43:19

OPO= 46.555 01PEI= 27.521 02PEO= 50.155 03DELP= 1.358 04TORQ= 20.493
06EXC10V= 10.006 RPM= 2617. 14TROT1=261.500 15TROT2=251.100
OTO=147.300 11TEI=143.500 12TEO=296.600 13THUB=249.200
PR=1.822 RPM=2617. A-E=.738 V-E=.886 T-E=.707

Y168:10:43:33

OPO= 46.499 01PEI= 27.523 02PEO= 50.102 03DELP= 1.352 04TORQ= 20.554
06EXC10V= 10.005 RPM= 2618. 14TROT1=261.700 15TROT2=255.800
OTO=147.700 11TEI=143.900 12TEO=297.000 13THUB=249.700
~~PR=1.820 RPM=2618. A-E=.737 V-E=.883 T-E=.702~~

Y168:10:48:57

OPO= 44.259 01PEI= 26.391 02PEO= 48.019 03DELP= 1.428 04TORQ= 20.673
06EXC10V= 10.006 RPM= 2694. 14TROT1=269.100 15TROT2=263.400
~~OTO=144.200 11TEI=142.000 12TEO=294.500 13THUB=256.000~~
PR=1.820 RPM=2694. A-E=.737 V-E=.895 T-E=.678

Y168:10:49:12

OPO= 44.329 01PEI= 26.467 02PEO= 48.079 03DELP= 1.428 04TORQ= 21.098
~~06EXC10V= 10.006 RPM= 2602. 14TROT1=271.000 15TROT2=268.100~~
OTO=144.100 11TEI=141.900 12TEO=294.300 13THUB=256.100

Y169: 10: 52: 12 *18 June 1982*

OPO= 42. 962 01PEI= 26. 431 02PEO= 51. 510 03DELP= . 852 04TORQ= 21. 518
06EXC10V= 9. 999 RPM= 2217. 14TROT1=248. 400 15TROT2=246. 200
OTO=133. 500 11TEI=131. 100 12TEO=300. 100 13THUB=223. 200

Y169: 10: 52: 32

OPO= 42. 947 01PEI= 26. 430 02PEO= 51. 528 03DELP= . 852 04TORQ= 21. 548
06EXC10V= 9. 999 RPM= 2219. 14TROT1=249. 100 15TROT2=247. 000
OTO=133. 700 11TEI=131. 200 12TEO=300. 600 13THUB=223. 900
PR=1. 950 RPM=2219. A-E=. 734 V-E=. 825 T-E=. 676

Y169: 11: 05: 59

OPO= 40. 276 01PEI= 25. 956 02PEO= 50. 195 03DELP= 1. 057 04TORQ= 20. 839
06EXC10V= 10. 000 RPM= 2403. 14TROT1=262. 900 15TROT2=261. 700
OTO=141. 200 11TEI=138. 900 12TEO=305. 900 13THUB=242. 100
PR=1. 934 RPM=2403. A-E=. 744 V-E=. 839 T-E=. 689

Y169: 11: 06: 16

OPO= 40. 301 01PEI= 25. 961 02PEO= 50. 245 03DELP= 1. 063 04TORQ= 20. 817
06EXC10V= 10. 000 RPM= 2399. 14TROT1=261. 700 15TROT2=260. 400
OTO=141. 200 11TEI=138. 900 12TEO=305. 800 13THUB=242. 900
PR=1. 935 RPM=2399. A-E=. 746 V-E=. 843 T-E=. 693

Y169: 11: 10: 35

OPO= 36. 761 01PEI= 25. 467 02PE = 48. 130 03DELP= 1. 311 04TORQ= 19. 809
06EXC10V= 10. 000 RPM= 2526. 14TROT1=261. 400 15TROT2=266. 400
OTO=142. 100 11TEI=139. 700 12TEO=299. 100 13THUB=247. 100
PR=1. 890 RPM=2526. A-E= 751 V-E=. 860 T-E=. 701

Y169: 11: 10: 54

OPO= 36. 481 01PEI= 25. 279 02PEO= 47. 769 03DELP= 1. 298 04TORQ= 19. 711
06EXC10V= 10. 000 RPM= 2530. 14TROT1=261. 600 15TROT2=268. 500
OTO=142. 000 11TEI=139. 800 12TEO=299. 300 13THUB=247. 300
PR=1. 889 RPM=2530 A-E= 730 V-E= 858 T-E= 697

Y169: 11: 14: 09

OPO= 38. 462 01PEI= 26. 152 02PEO= 50. 703 03DELP= 1. 440 04TORQ= 21. 072
06EXC10V= 9 999 RPM= 2636. 14TROT1=264. 100 15TROT2=276. 700
OTO=142. 400 11TEI=140. 600 12TEO=304. 100 13THUB=250. 400
PR=1. 939 RPM=2636. A-E=. 765 V-E=. 860 T-E=. 706

Y169: 11: 14: 24

OPO= 38. 493 01PEI= 26 178 02PEO= 30. 728 03DELP= 1. 440 04TORQ= 21. 115
06EXC10V= 10. 000 RPM= 2639. 14TROT1=264. 200 15TROT2=276. 400
OTO=142. 300 11TEI=140. 500 12TEO=304. 100 13THUB=250. 900
PR=1. 938 RPM=2639. A-E=. 764 V-E= 859 T-E=. 704

Y169: 11: 18: 42

OPO= 34. 034 01PEI= 25. 405 02PEO= 47. 417 03DELP= 1. 683 04TORQ= 19. 527
06EXC10V= 10. 000 RPM= 2702 14TROT1=262. 600 15TROT2=273. 000
OTO=139. 500 11TEI=138. 200 12TEO=294. 000 13THUB=255. 300
PR=1. 866 RPM=2702 A-E=. 750 V-E=. 870 T-E=. 702

```
06EXC10V= 10.000 RPM= 2704. 14TROT1=262.700 15TROT2=277.000
OTO=139.300 11TEI=138.100 12TEO=293.700 13THUB=255.700
PR=1.868 RPM=2704. A-E=.752 V-E=.869 T-E=.702

Y169:11:27:08

OPO= 34.289 01PEI= 25.256 02PEO= 48.255 03DELP= 1.783 04TORQ= 20.218
06EXC10V= 10.000 RPM= 2799. 14TROT1=264.800 15TROT2=266.000
OTO=139.600 11TEI=137.400 12TEO=297.200 13THUB=260.500
PR=1.911 RPM=2799. A-E=.760 V-E=.870 T-E=.702

Y169:11:27:23

OPO= 34.339 01PEI= 25.258 02PEO= 48.300 03DELP= 1.786 04TORQ= 20.177
06EXC10V= 10.000 RPM= 2798. 14TROT1=264.500 15TROT2=264.300
OTO=139.800 11TEI=137.600 12TEO=297.400 13THUB=260.400
PR=1.912 RPM=2798. A-E=.761 V-E=.872 T-E=.706

Y169:11:31:36

OPO= 34.354 01PEI= 25.305 02PEO= 48.322 03DELP= 1.785 04TORQ= 20.261
06EXC10V= 10.000 RPM= 2804. 14TROT1=268.900 15TROT2=265.800
OTO=141.100 11TEI=138.500 12TEO=299.800 13THUB=263.700
PR=1.910 RPM=2804. A-E=.754 V-E=.869 T-E=.700

Y169:11:31:58

OPO= 34.299 01PEI= 25.305 02PEO= 48.248 03DELP= 1.781 04TORQ= 20.232
06EXC10V= 10.000 RPM= 2802. 14TROT1=268.700 15TROT2=268.000
OTO=141.100 11TEI=138.500 12TEO=300.000 13THUB=264.100
PR=1.907 RPM=2802. A-E=.751 V-E=.868 T-E=.698

Y169:11:45:30

OPO= 34.301 01PEI= 25.303 02PEO= 48.560 03DELP= 1.782 04TORQ= 20.376
06EXC10V= 10.001 RPM= 2805. 14TROT1=272.900 15TROT2=266.000
OTO=141.800 11TEI=139.200 12TEO=303.300 13THUB=270.400
PR=1.919 RPM=2805. A-E=.748 V-E=.867 T-E=.701

Y169:11:45:46

OPO= 34.326 01PEI= 25.340 02PEO= 48.613 03DELP= 1.787 04TORQ= 20.441
06EXC10V= 10.001 RPM= 2800. 14TROT1=273.100 15TROT2=267.400
OTO=141.900 11TEI=139.300 12TEO=303.400 13THUB=270.200
PR=1.919 RPM=2800. A-E=.748 V-E=.869 T-E=.701

Y169:12:23:27

OPO= 34.311 01PEI= 25.299 02PEO= 49.587 03DELP= 1.802 04TORQ= 21.139
06EXC10V= 9.995 RPM= 2807. 14TROT1=264.300 15TROT2=235.600
OTO=139.100 11TEI=135.000 12TEO=304.200 13THUB=252.600
PR=1.960 RPM=2807. A-E=.746 V-E=.867 T-E=.700

Y169:12:23:41

OPO= 34.273 01PEI= 25.277 02PEO= 49.555 03DELP= 1.797 04TORQ= 21.068
06EXC10V= 9.996 RPM= 2804. 14TROT1=264.500 15TROT2=254.200
OTO=139.100 11TEI=134.900 12TEO=304.100 13THUB=252.900
```

```
Y169:17:19:26

OPO= 40.447 01PEI= 26.099 02PEO= 50.947 03DELP=  1.242 04TORQ= 21.620
06EXC10V= 10.001 RPM= 2510.  14TROT1=234.200 15TROT2=232.400
OTO=134.700 11TEI=131.600 12TEO=291.800 13THUB=198.300
PR=1.952 RPM=2510.  A-E=.778 V-E=.859 T-E=.694

Y169:17:19:43

OPO= 40.372 01PEI= 26.082 02PEO= 50.972 03DELP=  1.243 04TORQ= 21.539
06EXC10V= 10.001 RPM= 2516.  14TROT1=236.000 15TROT2=235.500
OTO=134.600 11TEI=131.600 12TEO=292.100 13THUB=199.000
PR=1.954 RPM=2516.  A-E=.778 V-E=.857 T-E=.696

Y169:17:44:46

OPO= 38.201 01PEI= 25.434 02PEO= 50.140 03DELP=  1.483 04TORQ= 21.138
06EXC10V= 10.002 RPM= 2717.  14TROT1=259.600 15TROT2=151.700
OTO=143.700 11TEI=140.200 12TEO=307.200 13THUB=233.000
PR=1.971 RPM=2717.  A-E=.770 V-E=.866 T-E=.709

Y169:17:44:59

OPO= 38.170 01PEI= 25.413 02PEO= 50.065 03DELP=  1.477 04TORQ= 21.167
06EXC10V= 10.001 RPM= 2715.  14TROT1=260.300 15TROT2=129.900
OTO=143.300 11TEI=139.900 12TEO=306.900 13THUB=233.600
PR=1.970 RPM=2715.  A-E=.768 V-E=.865 T-E=.706

Y169:17:49:00

OPO= 38.629 01PEI= 26.378 02PEO= 51.602 03DELP=  1.694 04TORQ= 21.927
06EXC10V= 10.001 RPM= 2805.  14TROT1=259.600 15TROT2=222.700
OTO=144.500 11TEI=140.700 12TEO=306.600 13THUB=236.500
PR=1.956 RPM=2805.  A-E=.766 V-E=.866 T-E=.700

Y169:17:49:14

OPO= 38.494 01PEI= 26.254 02PEO= 51.445 03DELP=  1.692 04TORQ= 21.821
06EXC10V= 10.001 RPM= 2807.  14TROT1=260.300 15TROT2=216.400
OTO=144.500 11TEI=140.600 12TEO=306.700 13THUB=236.800
PR=1.960 RPM=2807.  A-E=.767 V-E=.867 T-E=.703

Y169:17:54:23

OPO= 36.942 01PEI= 25.559 02PEO= 50.587 03DELP=  1.819 04TORQ= 21.596
06EXC10V= 10.001 RPM= 2903.  14TROT1=262.100 15TROT2=124.100
OTO=141.000 11TEI=137.300 12TEO=306.500 13THUB=238.600
PR=1.979 RPM=2903.  A-E=.764 V-E=.870 T-E=.705

Y169:17:54:43

OPO= 36.907 01PEI= 25.544 02PEO= 50.535 03DELP=  1.818 04TORQ= 21.533
06EXC10V= 10.001 RPM= 2906.  14TROT1=262.300 15TROT2=136.700
OTO=141.000 11TEI=137.800 12TEO=306.600 13THUB=240.900
PR=1.978 RPM=2906.  A-E=.763 V-E=.869 T-E=.705

Y169:18:00:58

OPO= 37.925 01PEI= 26.131 02PEO= 52.320 03DELP=  1.984 04TORQ= 22.432
06EXC10V= 10.001 RPM= 3002.  14TROT1=266.300 15TROT2=219.800
OTO=143.800 11TEI=140.000 12TEO=312.100 13THUB=244.100
PR=2.002 RPM=3002.  A-E=.765 V-E=.870 T-E=.707
```

```
OPO= 37.596 01PEI= 25.870 02PEO= 51.855 03DELP=  1.971 04TORQ= 22.242
06EXC10V= 10.001 RPM= 3003.  14TROT1=266.300 15TROT2=140.500
OTO=143.900 11TEI=140.100 12TEO=312.600 13THUB=244.400
PR=2.004 RPM=3003.  A-E=.765 V-E=.872 T-E=.709

Y169:18:03:33

OPO= 37.845 01PEI= 26.088 02PEO= 52.182 03DELP=  1.978 04TORQ= 22.375
06EXC10V= 10.001 RPM= 3006.  14TROT1=268.100 15TROT2= 86.300
OTO=143.000 11TEI=139.700 12TEO=313.100 13THUB=248.000
PR=2.000 RPM=3006.  A-E=.758 V-E=.869 T-E=.705

Y169:18:03:46

OPO= 37.860 01PEI= 26.093 02PEO= 52.207 03DELP=  1.978 04TORQ= 22.336
06EXC10V= 10.001 RPM= 3008  14TROT1=267.700 15TROT2= 95.100
OTO=142.900 11TEI=139.600 12TEO=313.100 13THUB=248.300
PR=2.001 RPM=3008.  A-E=.758 V-E=.868 T-E=.706

Y169:18:26:30

OPO= 37.756 01PEI= 25.931 02PEO= 52.102 03DELP=  1.971 04TORQ= 22.297
06EXC10V= 10.001 RPM= 3006.  14TROT1=256.100 15TROT2=-26.800
OTO=148.400 11TEI=143.400 12TEO=310.800 13THUB=226.400
PR=2.009 RPM=3006.  A-E=.796 V-E=.873 T-E=.712

Y169:18:26:45

OPO= 37.815 01PEI= 25.978 02PEO= 52.150 03DELP=  1.972 04TORQ= 22.240
06EXC10V= 10.001 RPM= 3005.  14TROT1=257.000 15TROT2= 36.500
OTO=148.900 11TEI=144.000 12TEO=311.400 13THUB=226.300
```

Appendix E

Data Reduction Equations

```
      END
      SUBROUTINE REDUCE(LOUTF)
      LOGICAL*1 LINE(82),CR,LF,TOY(15),DATA(405),SWITCH
      REAL M1,M2
      REAL K,K1,K2
      DIMENSION GAMS(78),PPRIME(78)
      COMMON/A/ADAT(20),AA(10),BB(10),IDD1,IDD2,RCON,NO,NCHAN(20)
     +, NPRT,DATA,NRPM,NBUSED
      COMMON/B/CR,LF,SS
      EQUIVALENCE (TOY(1),DATA(4))
C
C      DATA B,C,D2,F,FA,K,K1,K2/.44902,.984,.252,1.02097
C     + ,1.0,1.4,3.5,1.4286/
C
      DATA B,C,D2,F,FA,K,K1,K2/.64000,.984,.640,1.09617
     + ,1.0,1.4,3.5,1.4286/
C
      DATA GAMS/.000314,.000327,.000339,.000352,.000366,.000380,
     +.000394,.000409,.000424,.000440,.000457,.000473,.000491,.000509,
     +.000528,.000547,.000567,.000587,.000608,.000630,.000652,.000675,
     +.000699,.000723,.000749,.000775,.000801,.000829,.000857,.000886,
     +.000916,.000947,.000979,.001012,.001045,.001080,.001116,.001152,
     +.001190,.001229,.001268,.001309,.001351,.001395,.001439,.001485,
     +.001531,.001580,.001629,.001680,.001732,.001785,.001840,.001896,
     +.001954,.002013,.002074,.002137,.002201,.002266,.002334,.002438,
     +.002473,.002546,.002620,.002696,.002774,.002854,.002936,.003020,
     +.003107,.003194,.003284 .003376,.003471,.003568,.003667,.003768/
      DATA PPRIME/.1878,.1955,.2035,.2118,.2203,.2292,.2383,.2478,
     +.2576,.2677,.2782,.2891,.3004,.3120,.3240,.3364,.3493,.3626,
     +.3764,.3906,.4052,.4203,.4359,.4520,.4686,.4858,.5035,.5218,
     +.5407,.5601,.5802,.6009,.6222,.6442,.6669,.6903,.7144,.7392,
     +.7648,.7912,.8183,.8462,.8750,.9046,.9352,.9666,.9989,1.0321,
     +1.0664,1.1016,1.1378,1.1750,1.2133,1.2527,1.2931,1.3347,
     +1.3775,1.4215,1.4667,1.5131,1.5608,1.6097,1.6600,1.7117,
     +1.7647,1.8192,1.8751,1.9325,1.9915,2.0519,2.1138,2.1775,
     +2.2429,2.3099,2.3786,2.4491,2.5214,2.5955/
      EXC10V=ADAT(6)
      IF(EXC10V.EQ.0.0) GO TO 98
      PO  =(ADAT(1)*AA(1)+BB(1))*10./EXC10V
      PEI =(ADAT(2)*AA(2)+BB(2))*10./EXC10V
      PEO =(ADAT(3)*AA(3)+BB(3))*10./EXC10V
      DELP=(ADAT(4)*AA(4)+BB(4))*10./EXC10V
      TORQ=(ADAT(5)*AA(5)+BB(5))*10./EXC10V
      TO  =ADAT(11)
      TEI =ADAT(12)
      TEO =ADAT(13)
      THUB=ADAT(14)
      TROT1=ADAT(15)
      TROT2=ADAT(16)
      R1  =53.3
      R2  =FLOAT(NRPM)
C
C use parallel "RPM" read directly instead of IDD1
C
      R3  =RCON*R2
      PRATIO = PEO/PEI
      WRITE(1,1000) TEI,TEO,TORQ,PEI,PEO,NRPM,PO,DELP,PRATIO
 1000 FORMAT('0TEI=',F7.2,2X,' TEO=',F7.2,2X,'TORQ=',F7.3/
     +        ' PEI=',F7.2,2X,' PEO=',F7.2,2X,' RPM=',I7/
     +        '  PO=',F7.2,2X,'DELP=',F7.2,2X,'  PR=',F7.3)
      IF(NPRT.EQ.0) GO TO 7
C
C The write(2,) "line printer" were
C     formerly encodes,writel(x'70')
C
      WRITE(2,1100)(TOY(II),II=1,15)
 1100 FORMAT('0',80A1)
```

```
      C
      WRITE(2,1100)(TOY(II),II=1,15)
 1100 FORMAT('0',80A1)
      WRITE(2,1002) PO,PEI,PEO,DELP,TORQ
 1002 FORMAT(' 0PO=',F7.3,1X,'01PEI=',F7.3,1X,'02PEO=',F7.3,1X,'03DELP='
     +, F7.3,1X,'04TORQ=',F7.3)
      WRITE(2,1003) EXC10V,R2,TROT1,TROT2
 1003 FORMAT(1X,'06EXC10V=',F7.3,1X,'RPM=',F6.0,' 14TROT1=',F7.3,
     +' 15TROT2=',F7.3)
      WRITE(2,1005) TO,TEI,TEO,THUB
 1005 FORMAT(' 0TO=',F7.3,1X,'11TEI=',F7.3,1X,'12TEO=',F7.3,1X,'13THUB='
     +, F7.3)
      C
      C "N" option "NO"
      C       =1 is scan,conv
      C       =3 is scan,conv inp to drive "B"
      C       =2,4 is scan, conv, effficiencies
      C
 7    IF(NO.EQ.1) GO TO 99
      IF(NO.EQ.3) GO TO 20
 10   PR  =PEO/PEI
      TO  =TO+459.7
      TEI =TEI+459.7
      TEO =TEO+459.7
      T3  =TEI*(PR**.286-1)
      C
      C   A1  =(TEI-TEO)/T3
      C
      A1  =T3/(TEO-TEI)
      C
      E1  =PEI/(R1*TEI*12.)
      X   =68.388
      M1  =R2*X*E1
      LL  =IFIX(TO-491.19)
      RHOO=(PO-PPRIME(LL))*144./(53.32*TO)+GAMS(LL)*SS
      HW  =DELP*27.729
      R   =(PO-DELP)/PO
      YA  =SQRT(R**K2*K1*(1.-R**(1./K1))/(1.-R)
     + *(1.-B**4.)/(1.-B**4.*R**K2))
      M2  =359.*C*F*D2*FA*YA*SQRT(HW*RHOO)/60.
      E2  =.07652
      Q   =M2/E2
      C
      C   V   =M1/M2
      C
      V   =M2/M1
      C
      H2  =TORQ*R3/5252.
      C1  =.24
      H3  =.02356*M2*C1*TEI*(PR**.286-1)
      C
      C   H4  =H2/H3
      C
      H4  =H3/H2
      C
      WRITE(1,1004) V,H4
 1004 FORMAT(' Vol Eff=',F8.3,3X,'Isen Eff=',F8.3)
      IF(NPRT.EQ.0) GO TO 15
      WRITE(2,1006) PR,R2,A1,V,H4
 1006 FORMAT(' PR=',F5.3,1X,'RPM=',F5.0,1X,'A-E=',F4.3,1X,'V-E='
     +, F4.3,1X,'T-E=',F4.3)
 15   IF(NO.NE.4) GO TO 99
      C
      C "N" option = 4 means put to disk
      C
 20   WRITE(1,1011)
      WRITE(LOUTF,1013) (TOY(II),II=1,13)
```

```
     +, F4.3,1X,'T-E=',F4.3)
  15  IF(NO.NE.4) GO TO 99
C
C "N" option = 4 means put to disk
C
  20  WRITE(1,1011)
      WRITE(LOUTF,1013) (TOY(II),II=1,13)
      WRITE(LOUTF,1010) TEI,TEO,PEI,PEO,TORQ
      WRITE(LOUTF,1010) R2,TO,PO,DELP,TROT1,TROT2
      NBUSED=NBUSED+129
      IF(NO.NE.4) GO TO 99
  30  WRITE(1,1012)
      WRITE(LOUTF,1010) M2,M1,Q,PR,H3
      WRITE(LOUTF,1010) H2,A1,V,H4
      NBUSED=NBUSED+94
      GO TO 99
  98  WRITE(1,1014)
  99  RETURN
1010 FORMAT(6F10.4)
1011 FORMAT(' INPUT DATA IS STORED ON DISK')
1012 FORMAT(' OUTPUT DATA IS STORED ON DISK')
1013 FORMAT(13A1)
1014 FORMAT(' TURN ON POWER SUPPLY')
      END
      SUBROUTINE READC(PRT,INCHR)
      LOGICAL*1 PRT,INCHR,INPRT,ORE
      LOGICAL*1 STATUS,STATP,READY,RDA,OVERUN
      DATA RDA,ORE/X'40',X'02'/
      INPRT=PRT+1
      STATP=PRT+0
  10  STATUS=INP(STATP)
      OVERUN=STATUS.AND.ORE
      IF(OVERUN.EQ..TRUE.) WRITE(1,1001)
1001 FORMAT(4H ORE)
      READY=STATUS.AND.RDA
      IF(READY.EQ..FALSE.) GO TO 10
      INCHR=INP(INPRT)
      INCHR=INCHR .AND. X'7F'
      RETURN
      END
      SUBROUTINE WRITEC(PRT,OUTCHR)
      LOGICAL*1 PRT,OUTCHR,OUTPRT
      LOGICAL*1 STATUS,STATP,READY,TBE
      DATA TBE/X'80'/
      OUTPRT=PRT+1
      STATP=PRT+0
  10  STATUS=INP(STATP)
      READY=STATUS.AND.TBE
      IF(READY.EQ..FALSE.) GO TO 10
      CALL OUT(OUTPRT,OUTCHR)
      RETURN
      END
```

B. TYPE AXBDATA

```
    5
6.9933    .33955    46755
.832418   .38957    47253
2.5       -.1625    47220
-.3378    .0365     59167
-1.958    -.2863    1612
1.0
```

Appendix F

Reduced Data, Summary

Test Date: 8 June 1982

Rotor/Endplate Build Clearances: .006/.007
Compressor Inlet Temperature: 72F

TIME	RPM	PR	VE	AE	TE
16:37	1740	1.30	.79	.55	.48
16:42	1730	1.37	.77	.58	.52
16:47	1722	1.48	.76	.62	.56
16:54	1724	1.61	.70	.62	.55
17:01	1722	1.67	.67	.59	.53
17:06	1712	1.79	.63	.59	.51
17:13	1728	1.94	.60	.56	.50
17:20	1715	2.00	.60	.55	.49
17:27	1714	2.10	.57	.53	.47
18:12	2008	1.38	.81	.57	.54
18:17	2005	1.51	.78	.62	.58
18:20	1991	1.58	.76	.63	.58
18:26	1976	1.71	.71	.62	.57
18:33	1994	1.79	.70	.61	.57
18:53	1995	1.93	.66	.59	.55
19:00	1992	2.10	.64	.60	.54
19:04	1989	2.19	.62	.57	.52
19:15	2202	1.45	.80	.53	.54
19:22	2188	1.50	.78	.57	.56
19:26	2199	1.63	.76	.62	.59
19:30	2189	1.72	.74	.63	.59
19:34	2189	1.79	.72	.63	.59
19:41	2190	1.92	.70	.62	.58
19:46	2194	2.03	.68	.62	.58
19:51	2178	2.09	.67	.60	.56

Test Date: 9 June 1982

Rotor/Endplate Build Clearances: .0045/.0065
Compressor Inlet Temperature: 72F

TIME	RPM	PR	VE	AE	TE
18:00	2003	1.41	.86	.62	.58
18.04	2001	1.50	.83	.65	.60
18:08	1988	1.61	.80	.68	.63
18:11	1989	1.70	.79	.68	.63
18:15	2002	1.80	.77	.69	.63
18:19	1999	1.90	.75	.68	.62
18:28	1989	1.98	.73	.65	.61
18:35	1992	2.11	.71	.65	.61
18:37	1985	2.21	.70	.65	.60
18:42	2006	2.30	.69	.64	.59
18:51	2201	1.40	.85	.53	.56
19:01	2194	1.50	.85	.62	.60
19:04	2193	1.60	.84	.68	.63
19:12	2203	1.70	.82	.70	.65
19:15	2201	1.82	.81	.72	.66
19:20	2188	1.91	.77	.69	.64
19:23	2169	2.02	.78	.75	.66

Test Date: 10 June 1982

Rotor/Endplate Build Clearances: .0035/.0065
Compressor Inlet Temperature: 72F

TIME	RPM	PR	VE	AE	TE
16:27	2195	1.51	.87	.67	.61
16:31	2190	1.59	.85	.69	.63
17:06	2203	1.76	.83	.73	.66
17:08	2204	1.71	.84	.71	.66
17:11	2198	1.81	.83	.73	.68
17:14	2187	1.90	.80	.73	.67
17:18	2195	2.03	.80	.74	.68
17:21	2193	2.08	.78	.72	.67
17:23	2182	2.22	.77	.73	.66
17:25	2187	2.03	.78	.69	.67
17:29	2213	1.89	.80	.69	.67

Test Date: 10 June 1982, Vary Oil Flows

Rotor/Endplate Build Clearances: .0035/.0065
Compressor Inlet Temperature: 72F

TIME	RPM	PR	VE	AE	TE	OIL FLOWS
17:35	1797	1.65	.80	.64	.63	17.5, 12.5, 13
17:39	1799	1.64	.80	.64	.62	15, 12.5, 13
17:45	1796	1.64	.80	.66	.63	12.5, 12.5, 13
17:52	1800	1.65	.80	.67	.63	10, 12.5, 13
17:57	1800	1.65	.80	.67	.63	7, 12.5, 13
18:03	1800	1.64	.80	.67	.63	7, 11, 11
18:09	1799	1.63	.79	.66	.62	7, 8.5, 8.5
18:16	1800	1.63	.80	.66	.63	7, 7, 7
18:21	1803	1.62	.80	.65	.62	5, 5, 5
18:24	1799	1.65	.83	.68	.65	22, 5, 5
18:27	1795	1.68	.84	.70	.66	22, 16, 16
18:29	1798	1.68	.84	.70	.67	22, 19, 19

Test Date: 11 June 1982

Rotor/Endplate Build Clearances: .0025/.0065
Compressor Inlet Temperature: Noted below

TIME	RPM	PR	VE	AE	TE	TEI
16:47	1502	1.29	.83	.59	.51	70
17:16	2115	1.51	.86	.67	.61	72
17:22	2192	1.52	.87	.65	.61	72
17:27	2182	1.61	.85	.68	.64	72
17.31	2187	1.62	.86	.68	.64	72
17:35	2196	1.70	.84	.69	.66	72
17:41	2190	1.79	.83	.70	.66	73
17:47	2207	1.91	.81	.70	.66	74
17:52	2194	2.00	.80	.69	.66	76
17:58	2201	2.12	.79	.69	.66	77
18:05	2216	2.21	.80	.69	.66	78
18:22	2255	1.95	.83	.72	.68	97
18:24	2327	1.99	.83	.73	.68	100
18:33	2422	2.06	.87	.80	.73	134
18:38	2514	1.89	.89	.76	.71	134

Note: From 16:47 point to 17:27 point oil flows were 12,10,10. After 17:27 oil flows were 15,12,12.

Test Date: 16 June 1982

Rotor/Endplate Build Clearances: .002/.0065
Compressor Inlet Temperature: Noted below

TIME	RPM	PR	VE	AE	TE	TEI
18:53	2010	1.73	.82	.73	.64	97
19:00	2023	1.72	.84	.72	.66	111

Test Date: 17 June 1982

Rotor/Endplate Build Clearances: .002/.0065
Compressor Inlet Temperature: Noted below

TIME	RPM	PR	VE	AE	TE	TEI
10:10	2015	1.86	.82	.72	.66	116
10:17	2112	1.95	.83	.74	.68	126
10:20	2213	2.02	.83	.74	.69	130
10:27	2338	1.96	.85	.74	.69	136
10:32	2517	1.83	.88	.73	.70	141
10:41	2617	1.89	.88	.75	.71	140
10:48	2694	1.82	.90	.74	.68	142

Test Date: 18 June 1982

Rotor/Endplate Build Clearance: .002/.0065
Compressor Inlet Temperature: 131-141F

TIME	RPM	PR	VE	AE	TE	OIL FLOWS
10:52	2219	1.95	.82	.73	.68	12-14-14
11:05	2403	1.93	.84	.74	.69	12-14-14
11:10	2526	1.89	.86	.75	.70	
11:14	2638	1.94	.86	.76	.71	13-14-14
11:18	2702	1.87	.87	.75	.70	13-14-14
11:27	2799	1.91	.87	.76	.70	13-14-14
11:31	2804	1.91	.87	.75	.70	13-14-14
11:45	2805	1.92	.87	.75	.70	13-16-16
12:23	2807	1.96	.87	.75	.70	13-16-16
17:19	2510	1.95	.86	.78	.69	13-16-16
17:44	2717	1.97	.87	.77	.71	13-16-16
17:49	2805	1.96	.87	.77	.70	13-16-16
17:54	2903	1.98	.87	.76	.70	13-16-16
18:00	3002	2.00	.87	.76	.71	13-16-16
18:03	3006	2.00	.87	.76	.70	13-16-16
18:26	3006	2.01	.87	.80	.71	

Data Organization by pressure ratio

PR 1.90		PR 1.95		PR 2.00	
	11:10		10:52		17:54
	11:18		11:05		18:00
	11:27		11:14		18:03
	11:31		12:23		18:26
	11:45		17:19		
			17:44		
			17:49		